FISHERIES INVESTIGATIONS IN LAKES AND STREAMS

ANNUAL PROGRESS REPORT

Statewide Freshwater Fishery Research

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Study Title: STATEWIDE FISHERIES RESEARCH

Job Title: Redbreast Stocking Evaluation – Edisto River

Period Covered July 1, 2016 – June 30, 2017

Summary

An evaluation of the stocking of Redbreast Sunfish *Lepomis auritus* on the Edisto River was initiated in FY 2011 and continued through FY 2017. In the previous year, fish from the 2014 and 2015 year classes were collected from eight prescribed zones. Sampling zones include two zones immediately upstream of the stocking area, four within the stocking area, and two immediately downstream. Otoliths from these fish were supplied to our lab for processing and analysis.

A blind evaluation of oxytetracycline (OTC) marks was completed on known marked and unmarked Redbreast Sunfish from the 2015 year class, and 100% of fish were correctly classified. Age identification was completed for 2014 and 2015 year classes collected from the wild. This work included second reads for Redbreast Sunfish collected from the Edisto River during Fall 2016. Agreement with first reads was 95% and N=253 2015 year class fish were identified. Mark evaluations have been completed on those 2015 year class fish collected from within the stocking zone and 21 % over all were of hatchery origin. Fish collected in Spring 2016 were aged by first and second reads from Region 3 staff. A subsample (N = 25) was aged and agreement with Region 3 reads was 100%. N = 194 2014 year class fish were identified. Mark evaluations of these, and of remaining 2015 year class fish are in process.

Introduction

Redbreast Sunfish is a much sought after sport fish on the Edisto River. This is evidenced in collections made in 2004 that spanned a very high water event. Those collections suggest that once hydrologic conditions normalized, allowing for greater river access and angling, larger fish were quickly exploited and removed (Bulak 2005). The annual stocking of the Edisto River with Redbreast Sunfish began in 1995. This was in response to public concerns that introduced Flathead Catfish *Pylodictis olivaris* were negatively impacting the popular fishery. Records show approximately 13.7 million redbreast stocked in the river since 1995, with annual stocking ranging from 0.45-2.2 million.

The supplemental stocking of Redbreast Sunfish in Edisto River has never been evaluated. Collections of microtagged Redbreast Sunfish that were stocked in Little Pee Dee River from 1990 – 1992 suggested minimal contribution, though further sampling was recommended before drawing conclusions from the available data (Crochet and Sample 1993). Genetic survey of Redbreast Sunfish populations across five South Carolina drainages indicated Edisto River redbreast were markedly less diverse than redbreast populations from other drainages (Leitner 2006). This could be a result of lost diversity in the former hatchery population and its impact on the receiving population in the river, or could be an indication of bottleneck events occurring in the wild. To best manage this resource, we need a basic understanding of whether supplemental stocking is contributing to the Redbreast Sunfish population and fishery of the Edisto River. In the last year, a blind mark evaluation of known marked and unmarked fish from the 2015 year class was completed, fish from the 2014 and 2015 year classes were identified from field collections, and hatchery contribution of 2015 year class fish collected from within the stocking zone was evaluated.

Materials and Methods

We produced a blind set of known marked (N=36) and unmarked (N=14) 2015 year class fish. Otoliths from these fish were processed and evaluated for marks using the same procedures as are employed for study collections from the wild. Otoliths were cleaned if needed, embedded in epoxy resin, sectioned and polished, and viewed under ultra violet light to illuminate any OTC marks present. All otoliths were read by an experienced reader and classified as either marked or unmarked.

Otoliths from Redbreast Sunfish collected in the Fall of 2016 were received from Region 3 staff for second ageing reads, and for OTC evaluation. These samples were collected from eight prescribed sampling zones, which include two zones immediately upstream of the stocking area, four within the stocking area, and two immediately downstream (Figure 1). Ages were estimated from whole otoliths and compared to previous reads for agreement. Samples not agreed on by both readers were not considered further. All fish determined to be from the 2015 year class were set aside for OTC mark determination. After processing as described above, otoltihs were evaluated for marks by two readers. As with ageing, those samples not agreed on were not included in further analysis.

Prior to the 2016 fall collections, Region 3 staff collected redbreast April 20 to May 26, 2016. These collections were made in Spring to target the 2014 year class, which was not accessible due to high water in Fall of 2015. Both first and second ageing reads of these fish were completed by Region 3 in this project year, and otoltihs and data were received for OTC evaluation. A subset of N = 25 samples were aged by a third reader as a check.

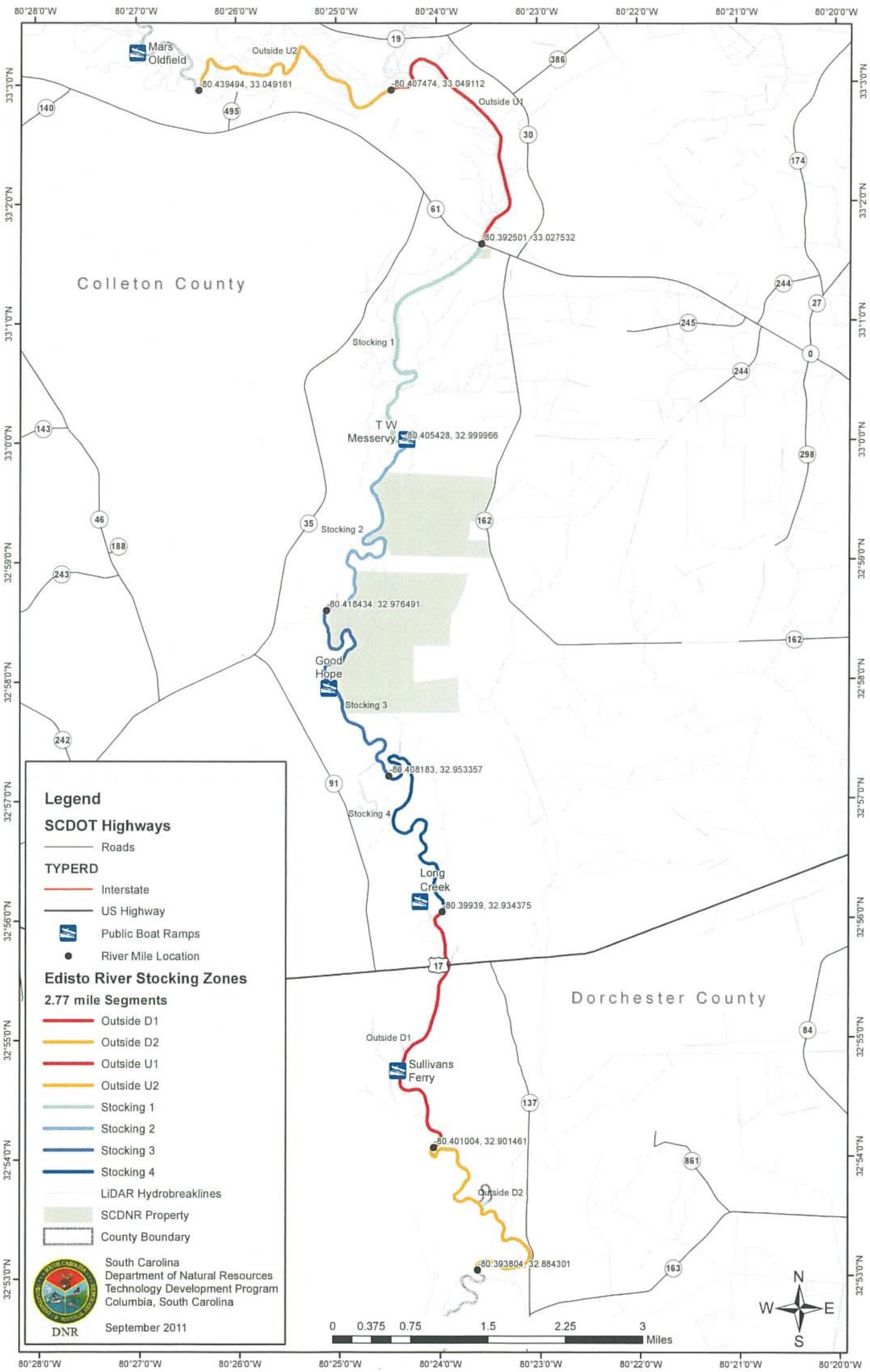

Figure 1. Sampling zones on the Edisto River, where Redbreast Sunfish were collected to evaluate the contribution of stocked fish to the 2010 and 2013 – 2015 year classes.

Results and Discussion

All 2015 year class otoliths evaluated in the blind set were correctly assigned as either marked or unmarked, indicating that identifying marks on this year class in the wild population can be accomplished with confidence. Second reads were completed for N = 308 fish collected in Fall of 2016. Agreement between readers was 95%, and N=253 fish were assigned by both readers to the 2015 year class. Those fish collected from the stocking zone sampling areas (N=146) have been evaluated for marks. Agreement between readers was 97%. Marked fish were collected from all four stock zones, with proportions of stocked fish within those zones ranging from 15% – 30%. This indicates a broader distribution of marked fish than was found in collections of previous year classes (Table 1).

A total of N = 194 fish collected in Spring of 2016 were estimated to be from the 2014 year class (Table 1). Agreement of reads for the subset of 25 samples was 100%. Evaluation of these samples for marks is in process.

In the coming year mark evaluations will be completed for remaining samples from the 2015 year class, and for all samples from the 2014 year class. A final recommendation regarding stocking of Redbreast Sunfish in the Edisto River will be made, and a final report will be compiled.

Table 1. Collection and mark evaluation results, by zone, for 2010, 2013-2015 year class Redbreast Sunfish collected from the Edisto River. A '.' indicates mark evaluations not yet completed.

Collection Zone	Year Class							
	2010		2013		2014		2015	
	N	Proportion Marked	N	Proportion Marked	N	Proportion Marked	N	Proportion Marked
Upstream 2	20	0	3	0	5	.	20	.
Upstream 1	25	0	19	0	4	.	32	.
Stock 1	45	.02	16	0	61	.	32	0.19
Stock 2	14	.07	21	.24	37	.	45	0.18
Stock 3	60	.28	14	.07	27	.	40	0.30
Stock 4	83	.12	14	0	21	.	26	0.15
Downstream 1	85	.03	33	.15	22	.	20	.
Downstream 2	45	.07	6	0	17	.	38	.
Total	**377**	**.09**	**126**	**.09**	**194**	**.**	**253**	**.**

Recommendations

Complete study. Complete mark evaluations for all zones for the 2014 year class, and for outside zones for the 2015 year class. Make recommendations based on results of this study regarding the continued stocking of Redbreast Sunfish in the Edisto River.

Literature Cited

Bulak, James S. 2005. Recruitment and growth of Edisto River Redbreast Sunfish. Study Completion Report. South Carolina Department of Natural Resources.

Crochet, Daniel W. and Christopher W. Sample. 1993. Fisheries Investigations in Lakes and Streams – District VII. Study Completion Report F-31-4. South Carolina Department of Natural Resources.

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Prepared By: Jean Leitner Title: Fisheries Biologist

Job Title: Crappie Data Compilation and Evaluation

Period Covered July 1, 2016 – June 30, 2017

Summary

The compilation and assessment of crappie *Pomoxis* spp. data continued. Records were added to master datasets for Lakes Greenwood, Thurmond, Murray, Wateree and Wylie. New records were primarily from trap netting, from both current and older files recently accessed. Data was also obtained from regional staff collections of crappie encountered during Largemouth Bass *Micropterus salmoides* electrofishing.

An update was presented to section staff at the annual biologist meeting. Initial recommendations included identifying priority populations, engaging angling groups, identifying studies to fill data gaps, and ensuring all sections are following the same ageing protocols.

Gaps in data include age at maturity. In an attempt to determine age at maturity we coordinated with Region 3 staff to collect crappie in late winter when ovaries should be completely developed, but pre-spawn. Fish (N = 127) were collected from Lake Murray with trap nets on February 15, 2017. Fish ranged in size from 131 – 370mm TL (total length) and from Age II – IX. While Age 0 and Age I crappie are typically collected during fall trap netting, these age classes were absent from our late winter nets. Gonads were examined for all fish. Despite the wide range in sizes and ages collected, all female fish collected were found to be in some state of positive ovarian development. It has proven difficult to collect crappie when mature and immature fish are co-distributed and equally vulnerable to capture, and when gonads will be in a state of development that make an assessment of maturity possible.

We used yield per recruit modeling on a representative population to assess how regulation changes may affect our populations. Results suggest that annual harvest may be higher than what is optimal to maximize yield and spawning potential. Consideration should be given to lower daily bag limits.

Introduction

Crappie are an economically and recreationally important sportfish in South Carolina. The species group is ranked first in number of days and second in total number of anglers based on South Carolina respondents to the 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (USFWS 2006). In addition to individual recreational anglers, a number of fishing clubs both local and national maintain active tournament schedules with frequent events on South Carolina lakes.

There are two species of crappie and both are present in South Carolina. Black Crappie *Pomoxis nigramaculatus* is native to all South Carolina drainages and is widely distributed throughout the state. White Crappie *P. annularis* was introduced. Though established in some areas of the Piedmont and Inner Coastal Plain regions, this species remains generally rare (Rohde et al. 2009). While White Crappie are collected and recorded in South Carolina in the routine survey of crappie, their numbers are very small. All of the data reported on here is for individuals identified as Black Crappie.

Crappie are often a difficult fish to manage (Maceina and Stimpert 1998). Growth and recruitment can vary widely both among populations, and among year classes within populations (Allen and Miranda 1998, 2001). Responses to management actions can vary widely as well (Wright et al. 2015). In an effort to better understand the dynamics of crappie populations in South Carolina, we have compiled statewide data produced largely through our routine effort to track populations via fall trap netting and have explored additional sampling strategies. In the last year work focused primarily on the analysis of data previously compiled. We evaluated data collected from 2005 - 2017. Additional fish were collected from Lake Murray in late winter in an attempt to assess age at maturity. Yield per recruit modeling in Fishery Analysis Modeling Software (FAMS) was conducted to evaluate minimum length, harvest regulations and reproductive potential at different harvest scenarios.

Materials and Methods

Data Compilation

Data analyzed was primarily provided by regional personnel, and was collected both in the routine sampling of crappie, and in sampling of other species that resulted in incidental catches of crappie. Methods included fall trap netting, winter gillnetting and spring electrofishing (targeting Largemouth Bass). Research staff collected data from crappie taken by tournament (Lakes Murray and Greenwood) and recreational angling (Thurmond Reservoir), and by spring electrofishing targeting crappie (Lake Wateree). Size, age and sex data were compiled from all methods and reservoirs into a standard format for archiving and analysis. Length data from all sampling methods was recorded in mm but some results are presented here in inches, which is the unit used in South Carolina harvest regulations.

Age and Growth

Ageing of fish in our database was primarily performed by regional personnel and data then provided to research for compilation. Fish collected by angling and some electrofishing collections were aged by research. From the last year winter trap net samples from Lake Murray were aged by research and those results are reported here. Ages were estimated by two independent readers and all agreed upon fish were retained in the database for further analysis.

Mean length at age and percent of fish vulnerable to harvest at age were calculated for Ages 0 - VIII for all populations except Lake Wateree. These calculations used only trap net data as other methods may be biased towards collecting the fastest growing individuals at an age. All Wateree data is from electrofishing or gillnetting. Differences among populations in mean length at age based on trap net data were evaluated using ANOVA. Von Bertalanffy growth curves were generated for all reservoirs using all aged fish. Growth curves were generated by the Von Bertalanffy equation

$$l_t = L_\infty \left(1 - e^{-K(t - t_o)}\right) \text{, where}$$

l=length, t = time in years, K = growth rate, and L_∞ = length where growth reaches zero.

Yield per Recruit Modeling

Yield per recruit modeling in Fishery Analysis Modeling Software (FAMS) was conducted to evaluate minimum length, harvest regulations and reproductive potential at a variety of plausible harvest scenarios. Harvest strategies were evaluated through total yield and mean size at harvest; reproductive potential was assessed by the Spawning Potential Ratio, defined as observed population fecundity divided by maximal population fecundity that would be obtained if there was no fishing mortality. In order to conduct this analysis, estimates of the relationship between length and weight, a Von Bertalanffy growth equation, estimates of fishing and natural mortality, longevity, fecundity, and age at maturity were needed. We evaluated the literature and long-term data from Thurmond reservoir and lakes Murray and Greenwood to obtain these estimates; an explanation of how each estimate was obtained follows.

Length-Weight Relationship

Linear regression of $\log_{10}$-transformed lengths and weights was performed to obtain the length-weight relationship for the three study reservoirs. All crappie in the long-term data sets with a length and weight recorded were used. The relationships were compared and a representative length-weight relationship was selected.

Longevity

In addition to the three reservoirs previously mentioned, we also inspected long-term data from lakes Wylie and Wateree. The age of the oldest and second oldest specimen in each reservoir was identified. Based on these results, we defined longevity for use in yield per recruit modeling.

Mortality

In a prior study, Hayes (2005) estimated mortality of crappie in Lake Greenwood. He estimated total annual mortality based on three years of trap net data (2002-2004) at 67% and annual fishing mortality at 43%, based on a reward tag exploitation study. Thus, annual fishing mortality in this population was estimated to be 64% of total annual mortality.

In this study long-term trap netting data were used from three study reservoirs. Lake Murray trap net collections were made in 2005 and 2007 - 2017. Because only a sample of presumed young of the year fish were aged, and the minimum size for ageing may have included Age I fish for some years, we did not calculate mortality from Age 0 to Age I in Lake Murray. Thurmond reservoir collections were made in 2000, 2002, 2006, 2008, 2010 - 2012, and 2016. Ninety-six (96) fish were not aged as all were ≤ 100 mm in length. These were assumed to be Age 0 fish based on length-frequency distribution of the age classes. Lake Greenwood collections were made in 2001, 2002, 2008 - 2010, 2014, and 2015. All collected fish from Lake Greenwood were aged. Total annual mortality (A) from one age class to the next was estimated using the equation:

$A = (N_t - N_{t+1}) \div N_t$; where N_t = Number at year t and N_{t+1} = Number at year t+1.

Total annual mortality was not estimated if the number at Age t+1 was greater than the number at Age t or if $N_t \leq 50$. This method assumes equal catchability of age classes N_t and N_{t+1}.

Von Bertalanffy growth equations

As described earlier, Von Bertalanffy growth curves were generated for all study reservoirs using PROC NLIN in SAS. Because exploitation data was only currently available for Lake Greenwood, we used the Lake Greenwood growth equation in yield per recruit modeling.

Fecundity

For fecundity we used the estimate obtained by Baker and Heidinger (1994) for black crappie in southern Illinois. Fecundity estimates were not available for South Carolina black crappie.

Age at Maturity

Trap netting was conducted in Lake Murray in the late winter of 2017 in an attempt to assess age at maturity. All fish collected were measured for TL (mm), weighed (g), sexed, and aged. Ovaries were evaluated visually for the presence of eggs, and gonadosomatic index [GSI = (gonad weight/body weight) X 100] was calculated. After weighing ovaries were stored frozen.

Yield per recruit modeling

Yield per recruit modeling was conducted using Fishery Analysis Modeling Software (FAMS). Yield, mean weight, and Spawning Potential Ratio were the key output metrics. As mentioned previously, Lake Greenwood length-weight and growth equations were incorporated in the model. Total annual mortalities of 55, 60, 65, and 70% were evaluated with fishing mortality comprising 60 and 67% of total annual mortality. Minimum length limits of 204, 229, 254, 279, and 304 mm TL were evaluated.

Results and Discussion

The compiled database includes 11,531 crappie collected from 2000 – 2017. Data are from Lakes Greenwood, Murray, Secession, Thurmond, Wylie, and Wateree. Some analyses reported here do not include data from all six lakes. Lake Wateree is the only study reservoir that is not routinely trap netted for crappie, therefore Lake Wateree is not included in mortality analyses. Inconsistencies in our Secession data became apparent in the process of compiling this report. For this reason we chose not to include Secession in length at age calculations. These inconsistencies will be further investigated and once cleared up Secession will be added to these results.

Collectively the majority (90%) of data in the compiled database is from trap netting. Five percent (5%) is from electrofishing, 3% is from gillnetting, and 2% is from angling. Length frequencies by lake and method illustrate that while trap netting effectively collects fish up to about 10 – 12 inches, alternative sampling methods have been valuable in the addition of larger fish to the data base. As examples, data from Lakes Thurmond, Greenwood and Murray are presented in Figures 1 - 3.

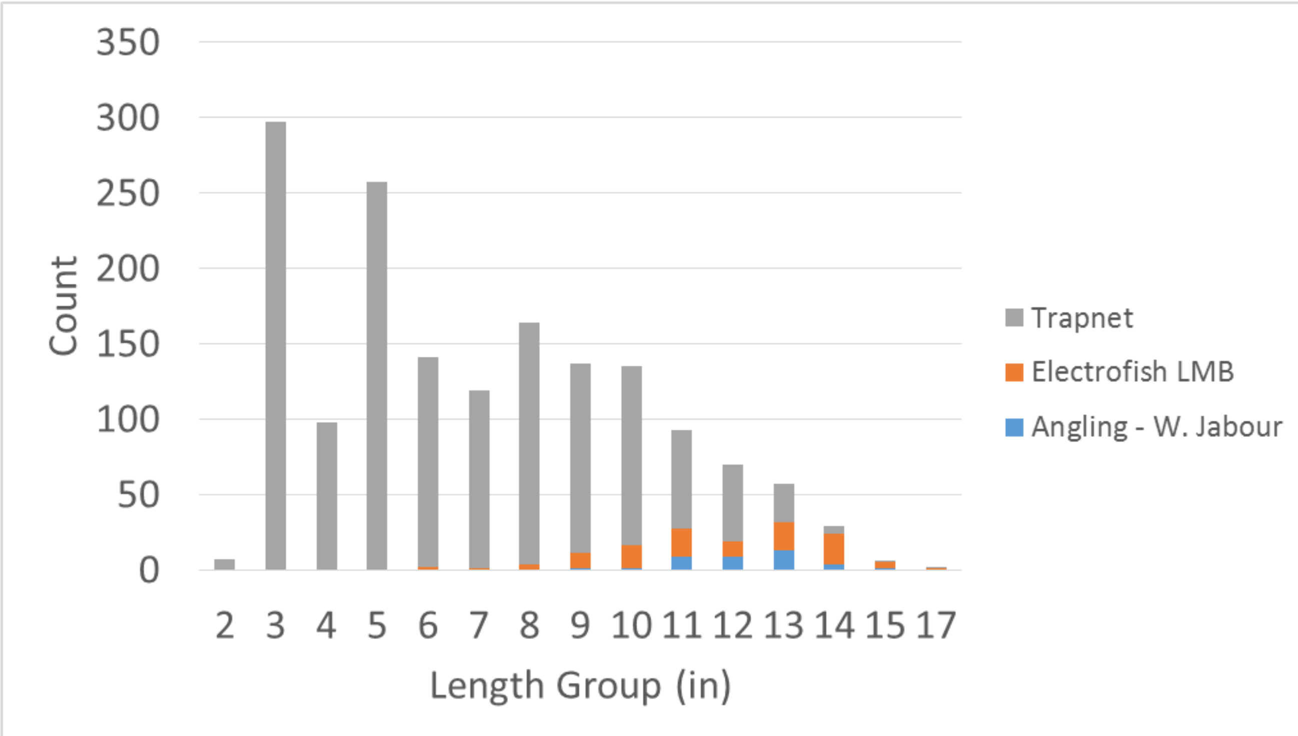

Figure 1. Lake Thurmond black crappie catch by length group for three collection methods; long term trapnet collection (Trapnet), Spring electrofishing targeting Largemouth Bass (Electrofish LMB), and angler donation (Angling – W. Jabour)..

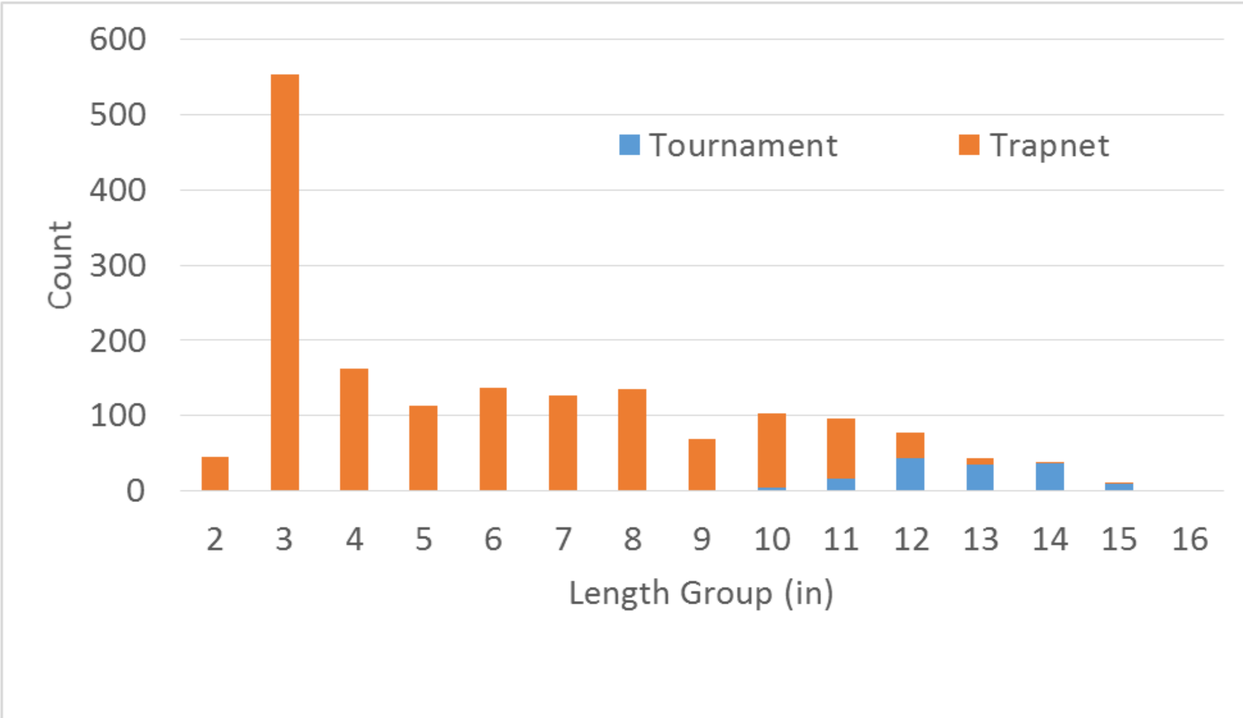

Figure 2. Lake Greenwood black crappie catch by length group for two collection methods; long term trapnet collection (Trapnet) and angling tournament collection (Tournament).

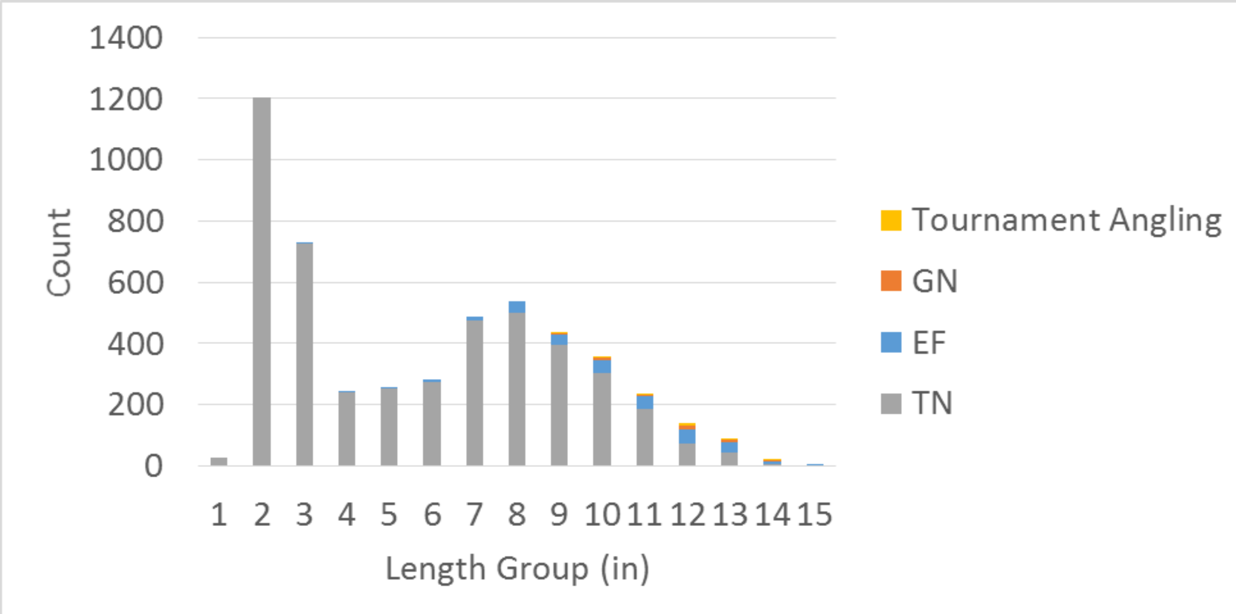

Figure 3. Lake Murray black crappie catch by length group for four collection methods; long term trapnet collection (TN), Spring electrofishing targeting Largemouth Bass (EF), gillnet (GN) and tournament angling.

Age and Growth

Mean length at age and percent of fish vulnerable to harvest at age indicate that before Age II few fish have entered our fisheries (Table 1). Lake Wylie is an exception as 75% of fish are vulnerable to harvest at Age I. For all populations the level of potential harvest of even Age II fish has potential to negatively impact spawning potential, as fish harvested at this age are expected to have had little opportunity to contribute to future year classes. This will be discussed further with modeling results.

Table 1. Mean total length at age (MN TL) and percent of fish vulnerable to harvest (i.e. % ≥ 203mm TL) based on long term trap net data.

Age	Reservoir											
	Thurmond			Greenwood			Murray			Wylie		
	MN TL (mm)	% ≥ 203mm	N	MN TL (mm)	% ≥ 203mm	N	MN TL (mm)	% ≥ 203mm	N	MN TL (mm)	% ≥ 203mm	N
0	78	0	365	79	0	776	89	0	534	80	3	71
1	139	6	565	157	7	407	181	29	1218	214	75	469
2	206	51	386	219	64	231	238	88	942	249	90	290
3	242	79	213	253	93	61	267	95	333	250	80	116
4	295	100	27	282	98	51	302	99	302	268	94	125
5	307	100	21	279	94	18	315	100	15	266	96	49
6	333	100	3	321	100	1	339	100	10	285	100	19
7	-	-	-	295	100	9	344	344	9	281	100	9
8	-	-	-	342	100	2	-	-	-	307	100	7

Differences among populations (lakes Wylie, Greenwood, Secession, Murray, and Thurmond) in mean length at age were not significant. This indicates trap netting is a consistent and appropriate method of assessing recruitment and growth in these Piedmont reservoirs.

Von Bertalanffy growth curves estimate that fish in most populations will reach harvestable size (203 mm) at around Age II (Table 2, Figure 4). Growth patterns for Murray, Greenwood, Thurmond, and Secession populations are similar, with the Murray population showing somewhat greater growth potential and Secession showing less between Ages 0 - IV. Wateree and Wylie differ in that these populations exhibit very fast growth early on, but an earlier flattening of their curve. This may be in part due to a strong 2010 year class dominating the data for both these populations. Of 82 black crappie collected from Lake Wateree during Region 2 largemouth electrofishing in April 2017, fish Age VII (2010 year class) represented 18% of crappie collected, and 100% of crappie over Age IV.

Table 2. Von Bertalanffy growth parameters calculated for black crappie populations in South Carolina reservoirs, and used in the generation of growth curves in Figure 1.

Parameter	**Reservoir**					
	Thurmond	**Greenwood**	**Wateree**	**Secession**	**Murray**	**Wylie**
L_∞	445.980	345.5	332.201	446.288	362.460	263.054
K	0.211	0.388	0.793	0.173	0.403	1.274
to	-0.260	-0.069	0.301	-0.471	-0.102	0.339

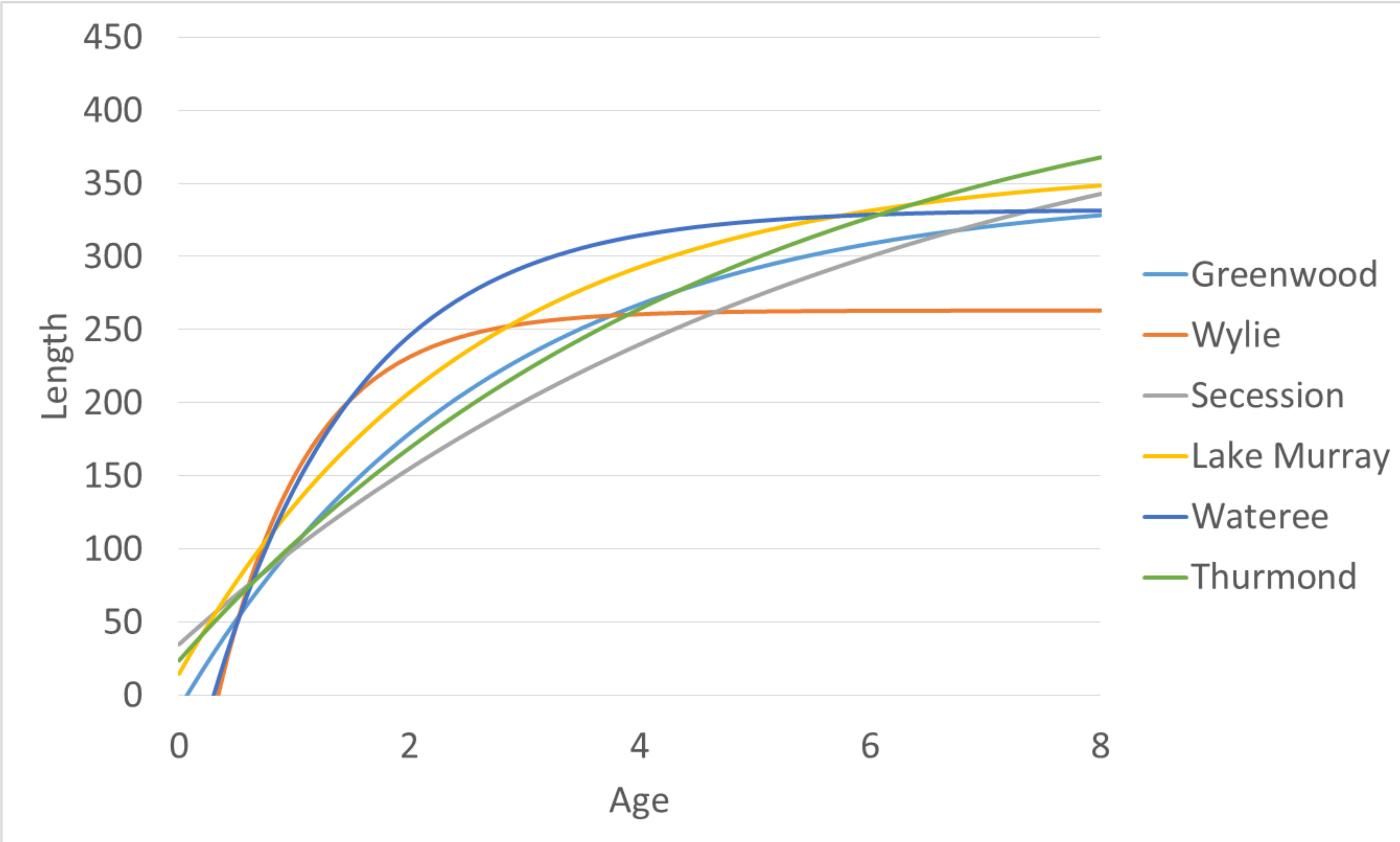

Figure 4. Von Bertalanffy growth curves for black crappie populations in Lakes Greenwood, Wylie, Secession, Murray, Wateree, and Thurmond. Length is total length in mm. Von Bertalanffy equation and parameters for each population are provided in text.

Yield Per Recruit Modeling

Length-weight relationship

Among the three study reservoirs, the relationship between total length (TL) and predicted weight (WT) was similar (Figure 5). As they were so similar, we elected to use the Lake Greenwood equation in yield per recruit modeling, as it was the intermediate equation. The obtained equations were:

- Lake Murray – $\log_{10}$ WT (g) = 3.375 * $\log_{10}$ TL -5.690; N = 5,026, $R^2 = 0.99$
- Lake Greenwood - $\log_{10}$ WT (g) = 3.268 * $\log_{10}$ TL -5.451; N = 5,026, $R^2 = 0.99$
- Thurmond Reservoir - $\log_{10}$ WT (g) = 3.301 * $\log_{10}$ TL -5.580; N = 1,758, $R^2 = 0.99$

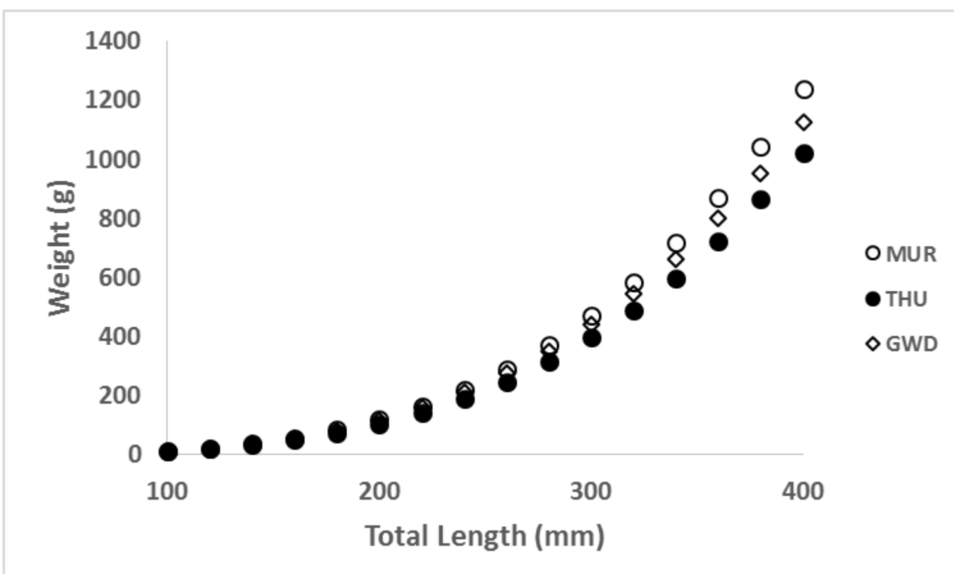

Figure 5. Predicted weight at length for Thurmond Reservoir (THU), South Carolina and Georgia, and lakes Murray (MUR) and Greenwood (GWD), South Carolina. Length-weight equations are provided in text.

Longevity

Based on the age of specimens in our long-term data sets, we defined age10 as the longevity of crappie in South Carolina for yield per recruit modeling, even though some older specimens were found. The potential of capturing older, larger specimens is gear dependent and, as explained earlier, gears that select for larger fish (angling, electrofishing) were minimally used during the collection of data. Data for most reservoirs was dominated by trap net data. The oldest and second oldest specimens recorded for each reservoir was:

- Lake Murray – oldest 12 (N=1), second oldest 11 (N=1)
- Thurmond Reservoir - oldest 11 (N=1), second oldest 7 (N=14)
- Lake Greenwood - oldest 8 (N=2), second oldest 7 (N=9)
- Lake Wateree - oldest 12 (N=1), second oldest 10 (N=2)
- Lake Wylie - oldest 10 (N=1), second oldest 9 (N=4).

Mortality

In trap net data, there was a noticeable increase in total annual mortality at Age II to Age III. This was expected as prior to Age II, some fish are not subject to fishing mortality. Total annual mortality from Age II to III was 65 and 74% in Lakes Murray and Greenwood, respectively. Lake Thurmond had the lowest total annual mortality from Age II to III at 44% (Table 3). A possible explanation for this relatively low mortality from Age II in Thurmond reservoir is that only 50% reach harvestable size of 8 inches (Table 1) while 64 and 88% attain harvestable size at Age II in Lakes Greenwood and Murray (Table 1), respectively. Though there is variability in the data, it does suggest a total annual mortality of approximately 65% or greater once crappie are vulnerable to fishing; this estimate agrees closely with the 67% estimate obtained by Hayes in Lake Greenwood.

Based on these results, we decided to evaluate total annual mortalities of 55, 60, 65 and 70% with fishing mortality accounting for 67% and 60% of total annual mortality in our yield per recruit modeling.

Table 3. Total annual mortality (A) between age-classes of Black Crappie in three South Carolina reservoirs. Estimates were obtained using long-term, fall trap netting data. The displayed estimate of A is from that age to the next age. Age is defined as the number of annuli present on the otolith.

Age	**Lake Murray**		**Thurmond reservoir**		**Lake Greenwood**	
	N	**A**	**N**	**A**	**N**	**A**
0	.	.	346	.	776	0.48
1	1218	0.23	478	0.20	407	0.43
2	942	0.65	381	0.44	231	0.74
3	333	0.71	212	0.87	61	0.16
4	95	0.84	27	.	51	0.65
5	15	.	.	.	18	.

Von Bertalanffy growth equation

We used the obtained growth equation for Lake Greenwood. That equation was:

- $TL_t = 345.5 * (1 - \exp^{-0.378*t - (-0.069)})$, where t = time in years.

Fecundity

We used the fecundity–length relationship found by Baker and Heidinger (1994). It was:

- log fecundity = -6.2192 + 4.6580 log length (mm); $R^2 = 0.7449$.

Age at Maturity

Spring trap-netting yielded 126 black crappie. All fish collected were Age II or older and agreement between readers was 100%. While mean GSI did vary by age (Table 4), eggs were observed in all ovaries collected. Thus, in our modeling assessment we assumed that all Age II females were mature. We do have concern that this was not a representative sample, as non-mature, Age II females may remain in offshore habitats where they are not vulnerable to trap-nets. No Age I females were collected which suggests this possibility. It has proven difficult to access adult crappie at both a time when mature and immature fish are co-distributed, and when gonads are at a stage of development when maturity of individuals can be assessed. Additional sampling is needed in the future to clarify and perhaps overcome this possible issue.

Table 4. Mean gonadosomatic index (GSI) by age for female black crappie collected from Lake Murray by trap netting in Spring 2017.

Age	**N**	**Mean GSI**
2	11	2.6
3	24	5.9
4	8	7.2
5	1	8.3
6	0	-
7	2	7.1

Yield per recruit modeling

At each evaluated minimum length and when fishing mortality was 67% of total annual mortality, yield was greatest when total annual mortality was 55%, progressively decreasing at 60, 65, and 70%. (Figure 6). When fishing mortality was decreased to 60% of total annual mortality, the same trend was observed but yield increased, due to the lowered rate of natural mortality (Figure 7). This trend causes some concern as trap net observed total annual mortalities exceeded 70% when crappie entered the fishery in the three reservoirs that were evaluated. This suggests that annual harvest may be too high to maximize yield. Consideration should be given to lower daily bag limits. In this effort, only Lake Greenwood was evaluated as length-weight and growth parameters were similar for all three populations. It is not expected that overall results would change greatly, but individual reservoirs can be modeled in the future using site specific parameters for each reservoir.

Modeling where fishing mortality was 67% of total annual mortality indicated that 204 and 229 mm minimum size limits consistently produced Spawning Potential Ratios (SPR) below 40% while a 254 mm minimum size limit approached or exceeded 40% (Figure 8). Crappie are a species that exhibits high variation in year class strength, generally attributed to environmental variability. However, increasing population fecundity has the potential to dampen the effects of environmental variability. Consideration should be given to SPR when setting regulations for crappie. In this exercise, it was assumed that all crappie mature at Age II, based on limited spring sampling data. Efforts should be taken to further define the age at maturity, as changes in the percent of each age class that spawns would affect SPR calculation.

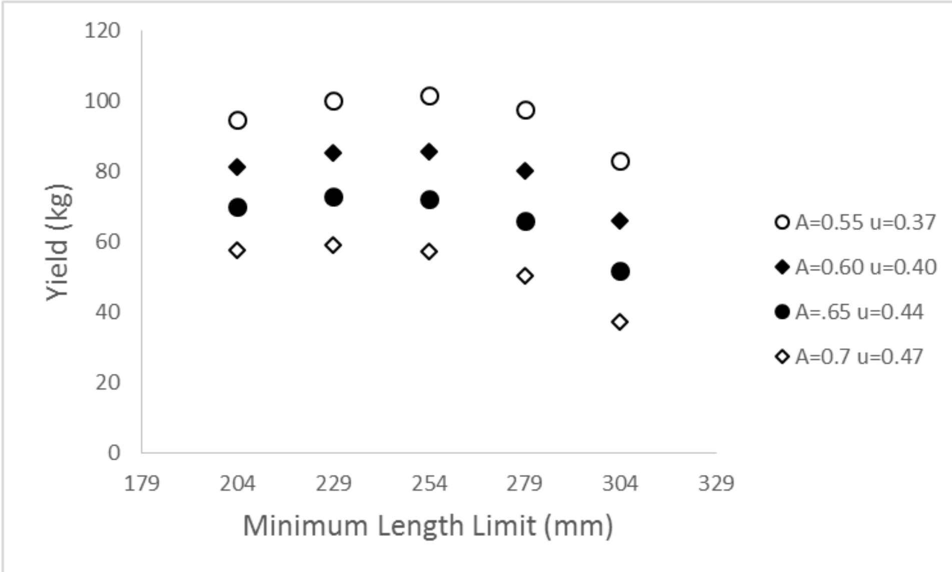

Figure 6. Yield per recruit evaluation of total yield (kg) of the crappie population in Lake Greenwood at varying minimum length harvest strategies and total annual mortalities. Fishing mortality was assumed to be 67% of total annual mortality.

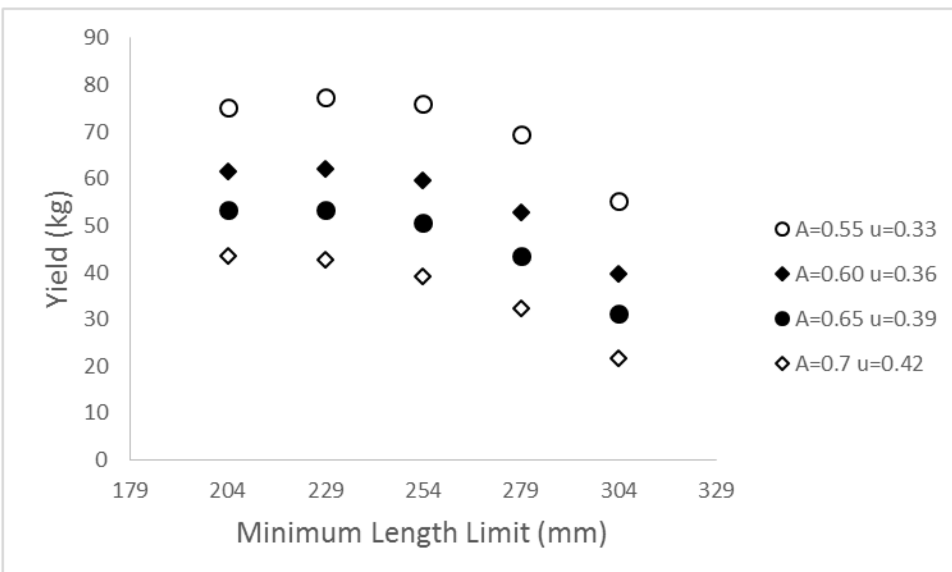

Figure 7. Yield per recruit evaluation of total yield (kg) of the crappie population in Lake Greenwood at varying minimum length harvest strategies and total annual mortalities. Fishing mortality was assumed to be 60% of total annual mortality.

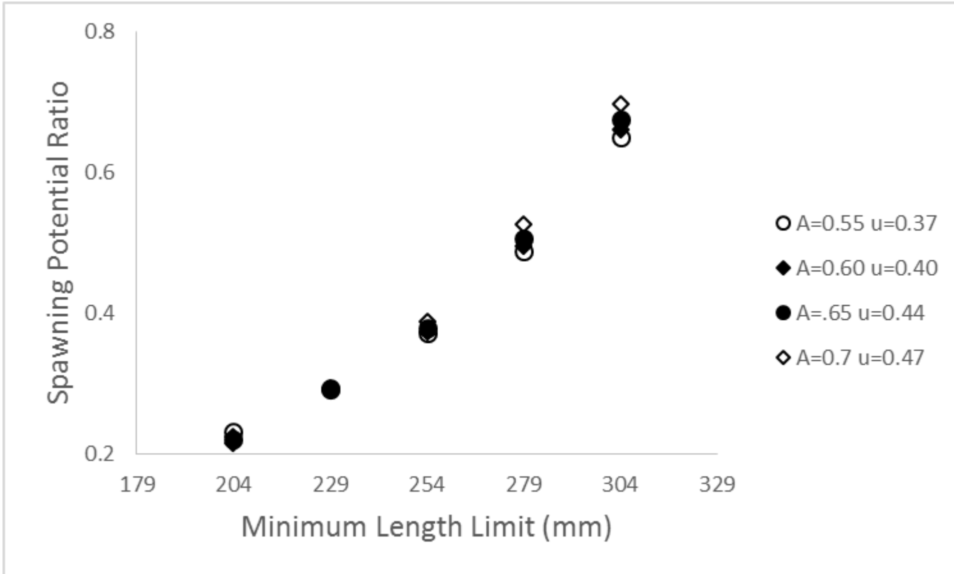

Figure 8. Yield per recruit evaluation of Spawning Potential Ratio for the crappie population in Lake Greenwood at varying minimum length harvest strategies and total annual mortalities. Fishing mortality was assumed to be 67% of total annual mortality.

Recommendations

Trap netting should remain as a core sampling device for Piedmont reservoirs. Managers should also consider exploitation studies on individual populations of interest. Our yield per recruit modeling suggested considering raising the minimum length from the current limit of 8 inches and reducing annual fishing mortality. Develop a Crappie Management team within the section. A primary charge of this group should be development of a statewide crappie management, monitoring, outreach, and research plan. A core goal should be to identify and work with crappie fishing clubs and tournament anglers as this is likely to prove mutually beneficial. Work with the outreach section to make results of the effort reported here available to the angling public.

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Prepared By: Jean Leitner — Title: Fisheries Biologist
Jim Bulak — Research Coordinator

Job Title: Assessing introgressive hybridization within and habitat requirements of Bartram's bass within its native range

Period Covered July 1, 2012 – June 30, 2017

Summary

Bartram's Bass *Micropterus sp. cf. cataractae* occupies a native range that is restricted to the Savannah Basin of South Carolina and Georgia. Introductions of the non-native Alabama Bass (*M. henshalli*) have put Bartram's Bass at risk due to introgressive hybridization. Effective conservation of this species requires comprehensive genetic baselines of tributary populations, a baseline evaluation of habitat, watershed conditions, and their relation to presence or absence of hybrids, and genetic tools that allow timely evaluation of changes in populations that may be related to time or to conservation actions. We partnered with University of South Carolina to develop genetic assays that would allow for fast evaluation while still providing results directly relatable to past sequence data on these populations. New assays were used to develop longitudinal genetic baselines on six South Carolina streams and on the Broad River sub-basin of Georgia. Fish for genetic analysis were collected from N=26 sites. Habitat parameters were measured and the relation of landscape level factors to the presence or absence of hybrids were evaluated.

Genetic baselines varied among streams. One South Carolina stream yielded only pure Bartram's Bass. For several streams upper sites yielded only pure Bartram's Bass but hybrids were collected from sites closer to downstream reservoirs. Two streams produced hybrids from all sites sampled. Both multiple logistic regression and Random Forests were used to model proportions of fish collected that were Bartram's Bass using multiple watershed variables as predictors. The best-fitting regression model included percent agriculture, longitudinal distance from downstream impoundment, and drainage area as predictors of probability of pure Bartram's Bass at a site

($p<0.001$; pseudo-$R^2=0.74$). Random forest analysis indicated that the single best predictor was human population density in the catchment, which was itself correlated with other anthropogenic disturbance variables. Catchments with human population densities below 45 per km^2 were more likely to support pure Bartram's Bass, as were those with agricultural land use below 25% of the catchment, impervious surface at very low levels (< 1 to 2%), and riparian canopy cover of at least 80% coverage. would be a desirable level to promote and protect habitat for Bartram's Bass.

Introduction

The Bartram's Bass is a nominal form of *Micropterus* that is currently considered a member of the Shoal Bass clade (*M. sp. cf. cataractae;* Freeman et al. 2015). It was previously described as Redeye Bass *M. coosae* (Hubbs and Bailey 1940). The Bartram's Bass native range is restricted compared to others of its genus and includes portions of the middle to upper Savannah basin of South Carolina and Georgia. Bartram's Bass native habitats include flowing, cool-water streams near and above the Fall Line (Rhode et al. 2009). In addition to native tributary habitats, Bartram's Bass thrived after impoundment within the Savannah River basin's man-made reservoirs (Koppelman and Garret 2002). The nominal species is one of two black bass native to South Carolina, and is identified by South Carolina's State Wildlife Action Plan as a Species of Highest Priority due to its restricted range and threats from introduced species (South Carolina Department of Natural Resources 2015). It is also one of three focus species in the National Fish and Wildlife Foundation's Native Black Bass Initiative (Birdsong et al. 2010).

Introductions of the non-native Alabama Bass (*M. henshalli*) into lakes Keowee and Russell in the 1980's have put Bartram's Bass at risk due to introgressive hybridization (Barwick et al. 2006). Genetic surveys in 2004 and 2010 showed that Alabama Bass had expanded within the

Savannah Basin, as had their hybrids with Bartram's Bass (Oswald 2007; Bangs 2011; Leitner et al. 2015). Both species were present in all four lakes surveyed, and in 2010 together they comprised from 48% to 68% of black bass collected from each reservoir. The 2004 survey of basin tributaries indicated that presence of Alabama Bass and their hybrids was limited in Bartram's Bass stream populations. In 2010 however an increase in Alabama Bass alleles was noted for several streams. Alabama Bass are known to take advantage of stream habitats, and the continued spread of hybridization throughout the basin is a conservation concern.

Human disturbance may facilitate hybridization in ecosystems. This idea goes back nearly 70 years when the concept of "hybridization of habitat" was introduced by Anderson (1948). With respect to terrestrial plant communities, Anderson asked "why is the backcrossing [introgression] largely in areas where natural conditions have been very much disturbed?" He argued that habitat disturbance can generate new niches favorable to hybrids, enhancing their fitness relative to native genotype(s). In more recent years, the association between habitat alteration and elevated levels of hybridization has been recognized as a contributor to loss of rare species through interbreeding with common or introduced species (Rhymer and Simberloff 1996). The phenomenon has been observed across multiple taxa, including terrestrial plants (Guo 2014), amphibians (Riley et al. 2003), birds (Maciorowski and Mirski 2014), and fish (Hasselman et al. 2014). Todesco et al. (2016) found in their recent literature survey examining the prevalence and causes of extinction through hybridization that the association with human activities was among the strongest reported.

In freshwater rivers and streams, habitat disturbance can result from multiple causes, including hydrologic alteration and both point and nonpoint pollution. Hasselman et al. (2014) discussed the disturbance created by damming rivers, which is currently a widespread occurrence in the upper Savannah River basin, and attributed the hybrid swarm of river herrings in a Virginia impoundment to disconnection and flow disruption of the riverine habitat. Additionally, human activity in watersheds, particularly land use, is linked to a suite of instream changes including altered flow regimes, siltation, channel alteration, changes in large woody debris, and poor water quality (Allan 2004).

To move conservation of Bartram's Bass forward a comprehensive genetic baseline of tributary populations was needed as well as a baseline evaluation of habitat, watershed conditions, and their relation to presence or absence of hybrids. Previous work has provided a genetic snapshot for sites on select streams, but still lacking has been an understanding of the upstream extent of hybridization throughout the Savannah system. Equally as important as the generation of new data is the availability of fast genetic assays for population evaluation, that eliminate the costly and time consuming need for direct sequencing of DNA, allowing us to evaluate populations and effects of conservation measures in near real time. Our objectives for this study were to

1. Develop hydrolosis probe type assays for black bass species present in the Savannah River basin, and use those assays to develop longitudinal genetic baselines for priority stream populations of Bartram's Bass,
2. Complete aquatic habitat assessments for priority stream sites and correlate conditions to land use in sub-basins sampled,
3. Identify barriers in place on priority streams, and evaluate the potential of barriers to block upstream migration of Alabama Bass and their hybrids,
4. Test the hypothesis that introgression in populations of black bass in our study streams was related to altered stream habitat, as indicated by measures of watershed disturbance.

Materials and Methods

Genetic assays were developed by our partner at the University of South Carolina Dr. Joe Quattro, and Dr. Matt Greenwold working as a post-doc in the Quattro Lab. Molecular Beacon software was used to identify suitable probe sequences for Actin, Calmodulin and ITS, the three nuclear loci determined by Oswald (2007) to distinguish between the species of black bass present in the Savannah Basin. Additionally the mtDNA locus ND2 was used to evaluate hybridization by direct sequencing and identification of haplotypes previously shown to be diagnostic for the species of black bass in question (Oswald 2007). Sequence identification and probe development proved complicated for two of three nuclear loci and alternative methods were employed, including development of pairs of probes for Calmodulin, and use of Confronting Two-Pairs Primers software (CTPP; Chuang et al. 2015; http://bio.kuas.edu.tw/ma-ctpp/availability.jsp) to design sets of amplification primers for ITS. Once developed, all assays were tested using a set of known Bartram's Bass, Alabama Bass, and hybrid samples that had previously been diagnosed by direct sequencing. For complete details of probe protocols please contact report coauthor Jean Leitner (South Carolina Department of Natural Resources).

Seven streams or stream systems were chosen for inclusion in this study (Table 1). Black bass collections were made from 26 sites within these chosen streams by backpack electrofishing where possible, and by angling where conditions precluded electrofishing. All fish encountered from the genus *Micropterus* were measured, photographed, and fin clipped. Fin tissues were placed in labeled cryotubes filled with 100% non-denatured ethanol, and were transported to the University of South Carolina for analysis using the assays developed.

Table 1. Sampling locations for black bass collected from Savannah basin streams. Stream sites for each Sub Basin / Stream are ordered downstream to upstream.

Sub-basin / Stream	**Site**	**Lat**	**Lon**
Tugaloo River			
Chatooga	Tugaloo-Opossum Creek	34.756373	-83.321644
	Camp Creek	34.767306	-83.322667
	Highway 76	34.815476	-83.306537
Chauga	Jenkins Bridge	34.631579	-83.174723
	Chau-Ram Park	34.682796	-83.14662
	Cobb Bridge	34.717967	-83.177349
	Riley Moore Falls	34.741165	-83.179523
Seneca River			
Eastatoee Creek	Hemlock Hollow	34.9514	-82.85613
	Eastatoee Baptist Church	34.9868	-82.84615
Little River	Lower – Burnt Tanyard	34.83675	-82.979056
	Middle – Trombley	34.849528	-82.979167
	Upper – Williams	34.853911	-82.982135
Twelvemile	Below Easley Central Dam	34.77654	82.77195
	Robinson Bridge	34.78209	-82.75442
	Souliri	34.79197	-82.75433
	Liberty Highway	34.802453	-82.749322
	Stewart Gin	34.81866	-82.75414
Savannah River			
Broad River system	Broad River – Anthony Shoals	33.9868	-82.648706
	Big Clouds Creek	34.02058	-83.07082
	South Fork Broad River	34.026959	-83.074364
	Broad River – Sandbar Kayak	34.154956	-83.071277
Stevens Creek	At 21	33.80482	-82.20903
	At 88	33.68778	-82.14837
	At 23	33.72832	-82.18256
	Upstream of Turkey Creek	33.77199	-82.1667
	At Parksville	33.78608	-82.18766

Instream habitat measurements were taken from fish collection sites where wading conditions allowed. Current velocity, depth and substrate were characterized for a 100-m stretch within each site, using the ‘zig zag’ method as described in the South Carolina Stream Assessment Standard Operating Procedures (M. Scott et al. 2009) adapted from Bevenger and King (1995). Measurements were taken at 50 points along the stream reach, moving in a zig-zag manner to proportionally represent all stream habitats (i.e. riffle, run, pool). At each point selected, depth (m) and water velocity (m/s; 0.6 depth) were recorded. Bottom substrate was blindly selected as the first object touched and categorized by size and type. Smaller portable rocks were measured by hand in mm. Large embedded rocks were estimated with a meter stick. Substrate categories and definitions are listed in Table 2. Wetted channel width was recorded every 20 m beginning at 0 m (N=6 points). ‘Deep’ habitat was defined as ≥ 1.5 m. Length and width of deep sections were measured to determine deep patch area. Total percentage of deep habitat (%DH) was determined.

Table 2. Substrate categories and definitions for habitat evaluations at Bartram’s Bass collection sites.

Substrate Type / Category Name	Description	Size
Inorganics		
0.5 mm sand	Silt, fine sand	< 1 mm
Intermediate	Sand, rock, boulders or sheet rock	> 1 mm - < 999 mm
Hard Bottom	Boulder or bedrock	> 999 mm
Organics		
FPOM	Fine particulate organic matter	< 1 mm diameter
CPOM	Coarse particulate organic matter	1 – 50 mm diameter
FWD	Fine woody debris	3-10 cm diameter, > 50 cm length
LWD	Large woody debris	> 10 cm diameter, > 50 cm length

For all sites, we obtained measures of watershed disturbance by linking site location to the National River Fish Habitat Condition Assessment database (NRFHCA; Wang et al. 2011). The NRFHCA hierarchical spatial framework and database provides spatial predictor data for catchments across the United States, and was created using the National Hydrography Dataset Plus v.1 (NHDPlus). The NHDPlus is a vector dataset describing hydrological networks and associated catchment spatial characteristics at a spatial scale of 1:100,000. The smallest basic spatial unit of the NHDPlus are fluvial networks represented by confluence to confluence stream reaches (flowlines). Within the NRFHCA database, each flowline is attributed with predictor data at two spatial levels: 1) local catchment spatial attributes, and 2) network catchments spatial attributes. Local catchments are defined as the elevation-derived drainage boundary that has a 1:1 relation to a given NHDPlus flowline. Network catchments are defined as the cumulative aggregation of local catchments that represent the entire upstream drainage boundary for a given NHDPlus flowline. Spatial predictor data attributed to each level includes a series of physical and human-disturbance factors that are known to influence stream characteristics and biota. The network catchment level better corresponds to a cumulative-effects perspective, therefore we selected attributes at this scale from the NRFHCA for use in our analysis.

Data for variables associated with land cover/use are derived from the National Land Cover Data 2006 set. Variables selected are mean annual precipitation and air temperature, channel slope, elevation, catchment area, length of roads, human population density, percent riparian forest canopy cover, impervious surface, urban and agricultural lands, and longitudinal distance from the nearest downstream impoundment.

Multiple logistic regression was used to model the proportion of fish collected that were genetically pure Bartram's Bass using the watershed variables selected as predictors. We also used a machine-learning method, Random Forests, to investigate the same models. Random Forests provides an alternative modeling paradigm to traditional statistics, where no a priori model is defined, there are no distributional assumptions, and complex data structures (non-linearity, high-order interactions) are accommodated (Breiman 2001, De'ath and Fabricus 2000).

Results

Actin probes were designed successfully that differentiate among species of black bass. Individual species demonstrated unique patterns while hybrids demonstrated elements of both (Figure 1). Calmodulin probe design was complicated by a pair of closely linked polymorphisms that differentiate Bartram's Bass and Alabama Bass. These polymorphisms are near the annealing site for the hydrolosis probe predicted by Molecular Beacon software. This software cannot identify a suitable probe when two site changes are contained within the probe sequence. To solve this, pairs of probes were designed that contain each pair of diagnostic base changes (four possible combinations) within the annealing site. As with the Actin probe, using the Calmodulin probe pure Bartram's Bass, Alabama Bass and hybrids were correctly identified by unique and distinguishable patterns (Figure 2).

For ITS, newly optimized CTPP software was used successfully to circumvent issues caused by the GC rich content of the locus. After optimization of PCR conditions, amplification primers designed using CTPP software identified all control individuals correctly. This set of CTPP identified primers was used in the final analysis of all fish collected.

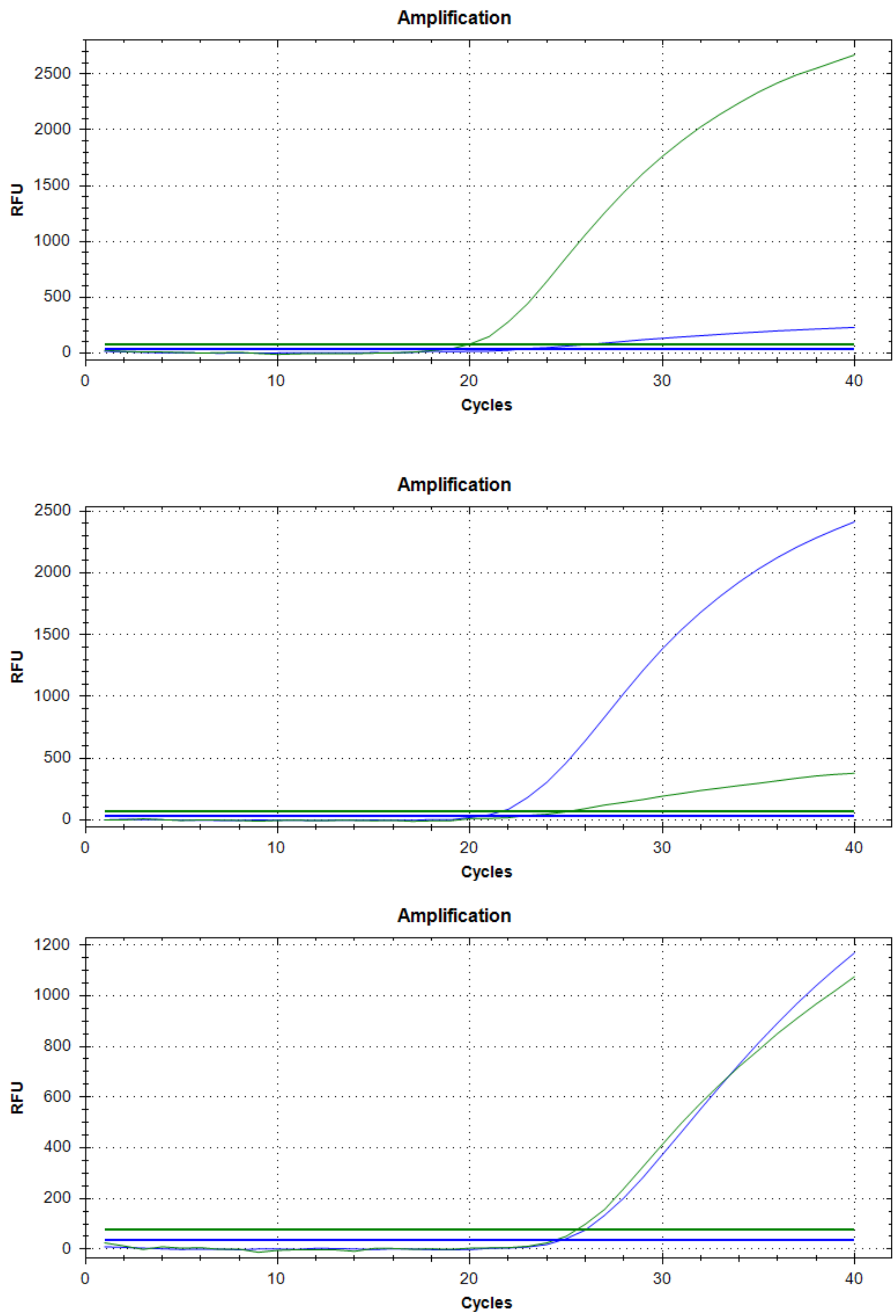

Figure 1. Shown are Actin hydrolysis probe results for Bartram's Bass (top), Alabama Bass (middle) and hybrid (bottom) samples. Number of PCR cycle runs (Cycles) are plotted with relative fluorescent units (RFU).

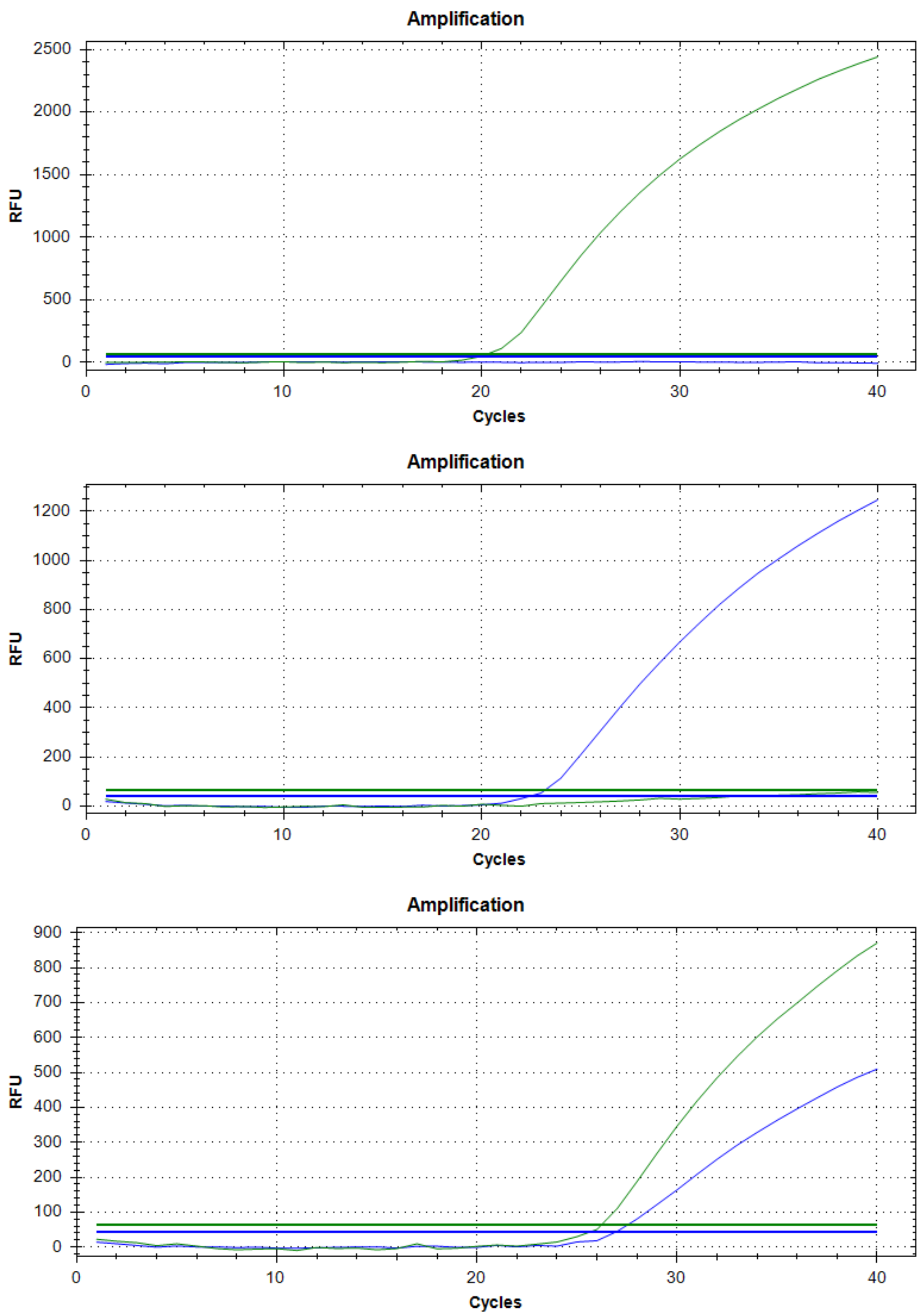

Figure 2. Shown are Calmodulin hydrolysis probe results for Bartram's Bass (top), Alabama Bass (middle) and hybrid (bottom) samples. Number of PCR cycle runs (Cycles) are plotted with relative fluorescent units (RFU).

We collected 376 black bass from 26 stream sites (Table 1). Hybrids were collected from at least one site on all but one stream / sub basin (Figure 3, Table 3). Proportions of hybrids varied widely however, both within and among streams. Two hybrids were taken from the upper site on Eastatoee Creek, comprising 11% of that collection. Hybrids were collected from throughout Twelvemile Creek (60 – 100%) and Little River (27 – 46%), while all but the lower most sites on Chauga River and Chattooga River produced just 0 - 5%. hybrids. In a pattern similar to Chauga and Chattooga Rivers, 2 of 3 fish collected at the Broad River lower most site were hybrids while no hybrids were collected from the 3 sites further up the system. For most rivers where hybrids were present, they were most prevalent at the lowermost sampling sites (Figure 3, Table 3). The exception was Twelvemile Creek, where hybrids were found throughout the stream at varying proportions, and were found both below and above a significant dam.

Stream habitat assessments were conducted at 19 of 26 sampling sites, including those on Eastatoee River, Stevens Creek, Little River, and Twelvemile Creek in South Carolina, and Clouds Creek and South Fork Broad River at Watson Mill Bridge State Park in Georgia (Table 4). Habitat assessments were not made at sites on the Chauga, Chattooga or Broad Rivers, as depth and high flows at these sites made assessments impossible. Because this data was not available for three of our streams, it is not included in modeling to assess factors related to hybridization metrics. Rather, models included measures of watershed disturbance for the catchment associated with each site as described in methods (Table 5).

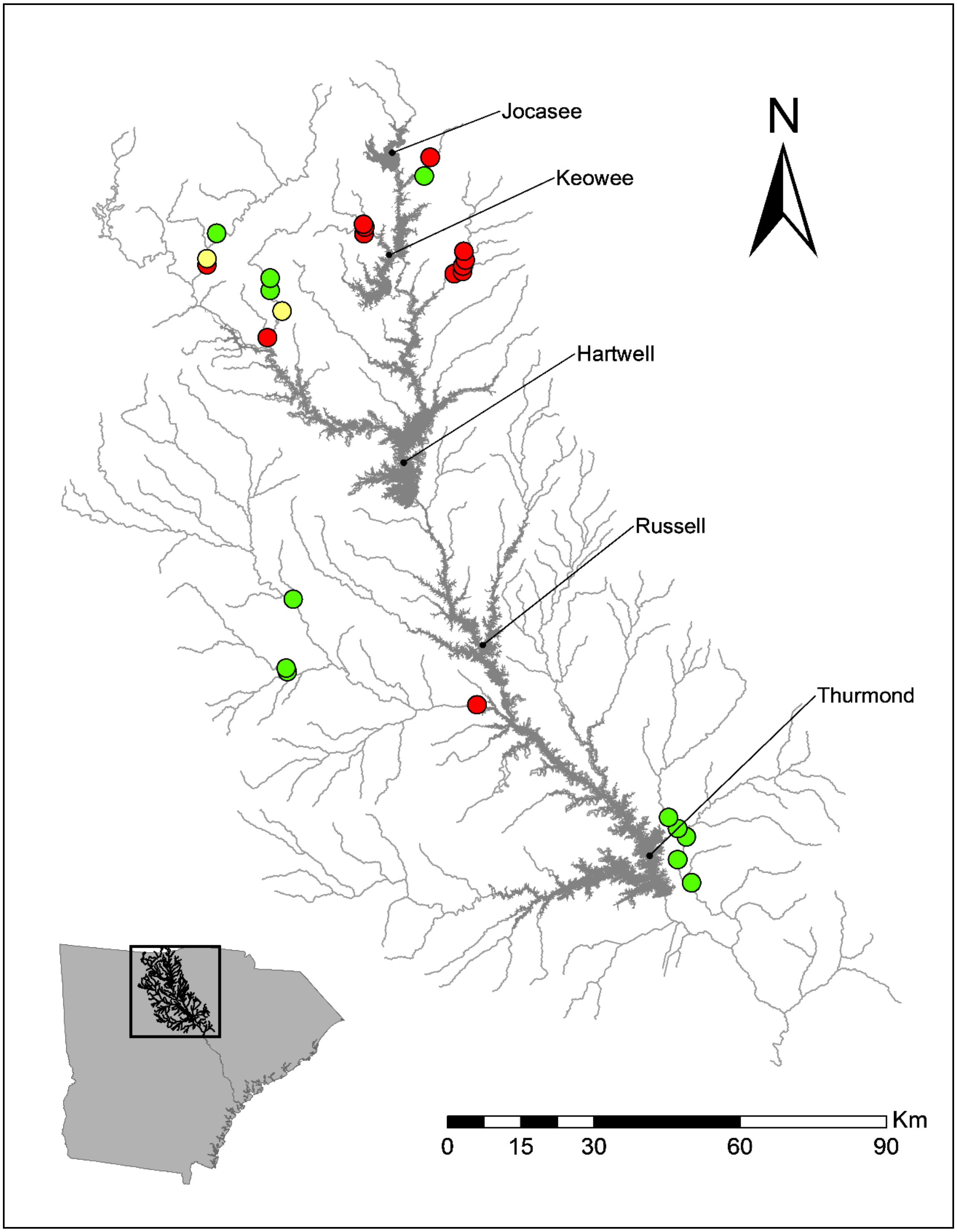

Figure 3. Savannah Basin tributaries showing black bass collection sites. Sites are color coded by the percent of fish collected that were pure Bartram's Bass; green = 100, yellow = 95 – 96, red = 0 – 89.

Table 3. Genetic results for black bass collected from Savannah basin streams. Stream sites for each Sub Basin / Stream are ordered downstream to upstream. Species (SPP) proportions of Bartram's Bass are proportions calculated from all Bartram's, Alabama, and hybrid bass collected. Nuclear (nDNA) and mitochondrial dna (mtDNA) proportions are numerical proportions of alleles or haplotypes specific to Bartram's Bass, across all bass collected. Locations can be found in Table 1.

Sub-basin/Stream	**Site**	**N Fish**	**Proportion Bartram's Bass**		
			SPP	**nDNA**	**mtDNA**
Tugaloo River					
Chatooga	Tugaloo-Opossum Creek	4	0.50	0.71	0.75
	Camp Creek	29	0.96	1.00	0.97
	Highway 76	31	1.00	1.00	1.00
Chauga	Jenkins Bridge	13	0.61	0.80	1.00
	Chau-Ram Park	21	0.95	0.95	1.00
	Cobb Bridge	23	1.00	1.00	1.00
	Riley Moore Falls	45	1.00	1.00	1.00
Seneca River					
Eastatoee Creek	Hemlock Hollow	1	1.00	1.00	1.00
	Eastatoee Baptist Church	18	0.89	0.98	1.00
Little River	Lower – Burnt Tanyard	24	0.54	0.76	0.92
	Middle – Trombley	38	0.58	0.86	1.00
	Upper – Williams	15	0.73	0.94	1.00
Twelvemile	Below Easley Central Dam	5	0.40	0.70	1.00
	Robinson Bridge	20	0.35	0.68	0.90
	Souliri	14	0.07	0.62	0.93
	Liberty Highway	3	0.00	0.22	0.67
	Stewart Gin	8	0.13	0.56	0.75
Savannah River					
Broad River system	Broad River – Anthony Shoals	3	0.33	0.78	0.33
	Big Clouds Creek	6	1.00	1.00	1.00
	South Fork Broad River	15	1.00	1.00	1.00
	Broad River – Sandbar Kayak	9	1.00	1.00	1.00
Stevens Creek	At 88	1	1.00	1.00	1.00
	At 23	2	1.00	1.00	1.00
	Upstream of Turkey Creek	2	1.00	1.00	1.00
	At Parksville	3	1.00	1.00	1.00
	At 21	23	1.00	1.00	1.00

Table 4. Calculated habitat variables by sample location, with mean and median values for each stream; Twelvemile Creek, Eastatoee Creek, Little River, Steven's Creek, Big Clouds Creek, GA and South Fork Broad River, GA.

Stream / Site	Habitat Parameter							
	Depth (m)		Velocity (m/s)		Median Substrate Diameter (mm)	Mean Width (m)	Large Woody Debris %	Deep Habitat %
	Mean	Standard Deviation	Mean	Standard Deviation				
Eastatoee Creek								
Hemlock Hollow	0.41	0.16	0.30	0.24	47.00	14.67	0	0
Eastatoee Baptist Ch.	0.39	0.23	0.37	0.25	25.00	10.75	4.00	5.21
Little River								
Lower – Burnt Tanyard	0.51	0.23	0.29	0.24	> 999.0	31.25	2.00	15.46
Middle – Doc Trombley	0.36	0.18	0.27	0.28	> 999.0	19.5	0	1.23
Upper – Williams	0.46	0.19	0.25	0.21	41.0	17.58	0	8.42
Twelvemile Creek								
Below Easley Central Dam	0.34	0.17	0.46	0.29	3.00	30.83	0	0
Robinson Bridge	0.42	0.12	0.34	0.19	0.50	17.00	22.0	0
Souliri	0.39	0.18	0.34	0.30	5.00	21.75	2.00	0.59
Liberty Highway	0.42	0.16	0.25	0.13	1.00	19.42	20.00	0
Stewart Gin	0.48	0.18	0.37	0.23	2.00	12.00	4.00	0
Broad River System								
Big Clouds Creek	0.30	0.15	0.31	0.27	3.18	19.75	0.04	0
South Fork Broad River	0.41	0.20	0.29	0.32	542.33	46.42	0	10.99
Stevens Ck.								
Highway 88	0.36	0.21	0.06	0.11	2.00	13.17	20.00	0
Highway 23	0.54	0.17	0	0.01	> 999.0	22.80	4.00	0
Blair Rd.	0.52	0.24	0.01	0.04	192.5	18.00	12.00	8.89
Parksville	0.25	0.16	0.06	0.09	44.0	16.08	10.00	9.95
Highway 21	0.33	0.16	0.06	0.13	> 999.0	14.40	2.00	0

Table 5. Catchment information for study streams from the National River Fish Habitat Condition Assessment, except for the distance measures. Ranked distance for sites on each stream is numbered beginning at the downstream-most site closest to impoundment; longitudinal distance is site distance measured in km from downstream impoundment.

	Mean annual precip. (mm)	**Mean annual air temp. (C°)**	**Channel slope (m/100m)**	**Elev. (m)**	**Catchment area (km^2)**	**Length of Roads (km/km^2)**	**Human Pop. Density ($\#/km^2$)**	**Riparian Forest Canopy Cover (%)**	**Impervious Surface Cover (%)**	**Urban Land Cover (%)**	**Agricultural Land Cover (%)**	**Longitudinal Distance from Impoundment (km)**	**Ranked Distance**
Chatooga River													
Tugaloo-Possum Creek	1632.41	14.1	18.87	396.13	702.49	1086.08	9.11	81.24	0.45	5.39	3.50	0.40	1
Camp Creek	1637.34	14.1	13.58	418.12	684.78	1063.78	9.21	81.40	0.46	5.45	3.50	2.12	2
Highway 76	1660.92	14.0	10.57	435.36	527.24	691.99	4.38	84.66	0.20	3.74	2.14	9.35	3
Chauga River													
Jenkins Bridge	1449.56	15.4	5.33	230.80	207.84	327.29	14.00	74.35	0.28	3.60	6.02	4.69	1
ChauRam Park	1507.01	15.1	4.96	266.07	173.62	260.72	5.78	75.90	0.23	3.39	5.35	10.82	2
Cobbs Bridge	1530.25	14.9	5.45	287.18	150.92	222.54	5.81	76.22	0.20	3.21	5.24	17.61	3
Riley Moore Falls	1573.99	14.7	8.23	307.65	145.10	215.93	5.82	75.77	0.20	3.28	5.42	19.49	4
Eastatoee Creek													
Hemlock Hollow	1659.78	15.2	8.73	313.28	81.46	103.40	4.08	85.05	0.07	2.60	2.14	1.46	1
Eastatoee Baptist Church	1719.22	14.7	12.83	399.69	66.17	82.65	3.64	86.50	0.06	2.50	2.07	7.98	2
Little River													
Lower – Burnt Tanyard	1632.86	15.2	6.95	284.78	190.15	333.00	14.36	73.24	0.35	3.93	6.49	1.59	1
Middle – Doc Trombley	1642.36	15.2	6.99	279.23	143.56	254.37	14.76	74.50	0.34	3.98	6.03	3.63	2
Upper - Williams	1642.36	15.2	6.99	279.23	143.56	254.37	14.76	74.50	0.34	3.98	6.03	5.24	3
Twelve Mile Creek													
Below Easley Central Dam	1418.50	15.4	6.93	267.17	334.06	1050.40	72.66	49.03	1.97	12.17	20.85	5.29	1
Robinson Bridge	1405.70	15.5	4.60	257.33	310.76	979.50	75.39	48.99	2.02	12.26	20.81	7.38	2
Souliri	1413.16	15.5	5.06	278.22	268.85	830.33	64.87	50.06	1.74	11.37	21.10	8.99	3
Liberty Highway	1413.16	15.5	5.06	278.22	268.85	830.33	64.87	50.06	1.74	11.37	21.10	10.97	4
Stewart Gin	1420.74	15.5	4.00	276.69	220.38	643.85	59.82	51.96	1.55	10.27	19.87	14.19	5

Table 5. Continued

	Mean annual precip. (mm)	Mean annual air temp. (C°)	Channel slope (m/100m)	Elev. (m)	Catchment area (km^2)	Length of Roads (km/km^2)	Human Pop. Density ($\#/km^2$)	Riparian Forest Canopy Cover (%)	Impervious Surface Cover (%)	Urban Land Cover (%)	Agricultural Land Cover (%)	Longitudinal Distance from Impoundment (km)	Ranked Distance
Steven's Creek													
Hwy 88	1199.95	16.8	3.83	76.46	1469.62	2273.31	12.56	57.16	0.55	5.49	10.56	16.21	1
Hwy 23	1201.84	16.7	3.43	84.17	1408.72	2200.24	12.97	57.08	0.56	5.59	10.61	22.57	2
Blair Rd.	1205.04	16.7	2.23	87.07	644.15	1033.43	16.01	56.25	0.69	7.12	11.68	29.15	3
Parksville	1205.44	16.7	1.83	90.32	638.69	1028.85	16.11	56.24	0.70	7.17	11.76	32.32	4
Hwy 21	1207.25	16.6	2.31	103.01	593.35	970.05	16.99	55.46	0.74	7.41	12.36	35.91	5
Broad River System													
Big Clouds Creek	1246.80	15.9	2.68	172.05	123.16	195.38	10.33	42.68	0.64	5.67	34.24	53.58	1
South Fork Broad R. Watson Mill State Pk.	1246.80	15.9	3.19	178.32	359.67	847.34	30.38	40.92	1.74	10.93	33.82	54.07	2

The best-fitting multiple linear logistic regression model relating landscape factors to hybridization included percent agriculture, longitudinal distance from downstream impoundment, and drainage area as predictors of probability of pure Bartram's Bass at a site ($p<0.001$; pseudo-$R^2=0.74$; Table 6, Figure 4). Random forest regression analysis indicated that the single best predictor of pure Bartram's Bass was human population density in the catchment, which was itself correlated with other anthropogenic disturbance variables such as agriculture (Pearson's $r=0.61$), impervious surface ($r=0.94$), and riparian canopy cover ($r=0.66$). The partial dependence plots from the random forest output show the functional relationship of the predictors with the response variable, holding other predictors constant (Figure 5).

Table 6. Best fitting multiple logistic regression on proportion of bass collected that were pure Bartrams using longitudinal distance from downstream impoundment, agricultural land cover, and catchment area as predictors.

	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	0.539470	0.404647	1.333	0.18247
Long. Distance	0.232769	0.042018	5.540	3.03e-08
Agricultural Land	-0.240839	0.029781	8.087	6.12e-16
Catchment Area	0.003708	0.001278	2.901	0.00372

Null deviance: 185.647 on 23 degrees of freedom
Residual deviance: 24.893 on 20 degrees of freedom
Pseudo-R^2 = 0.74

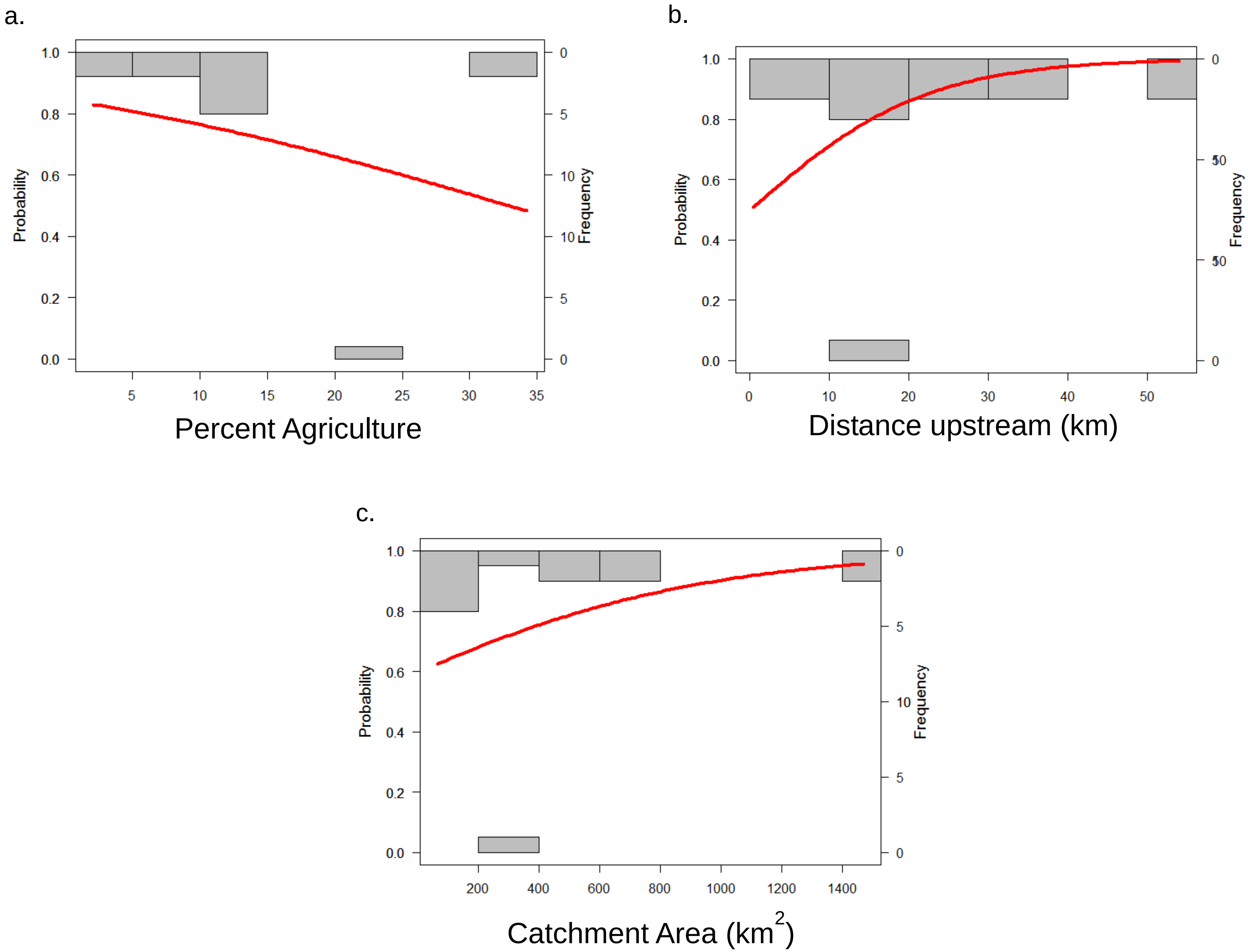

Figure 4. Plot of the marginal effect of catchment predictors (a) percent agriculture, (b) distance upstream (km) and c. catchment area (km^2) on the probability of bass being pure Bartram's, based on the best-fitting multiple logistic regression model.

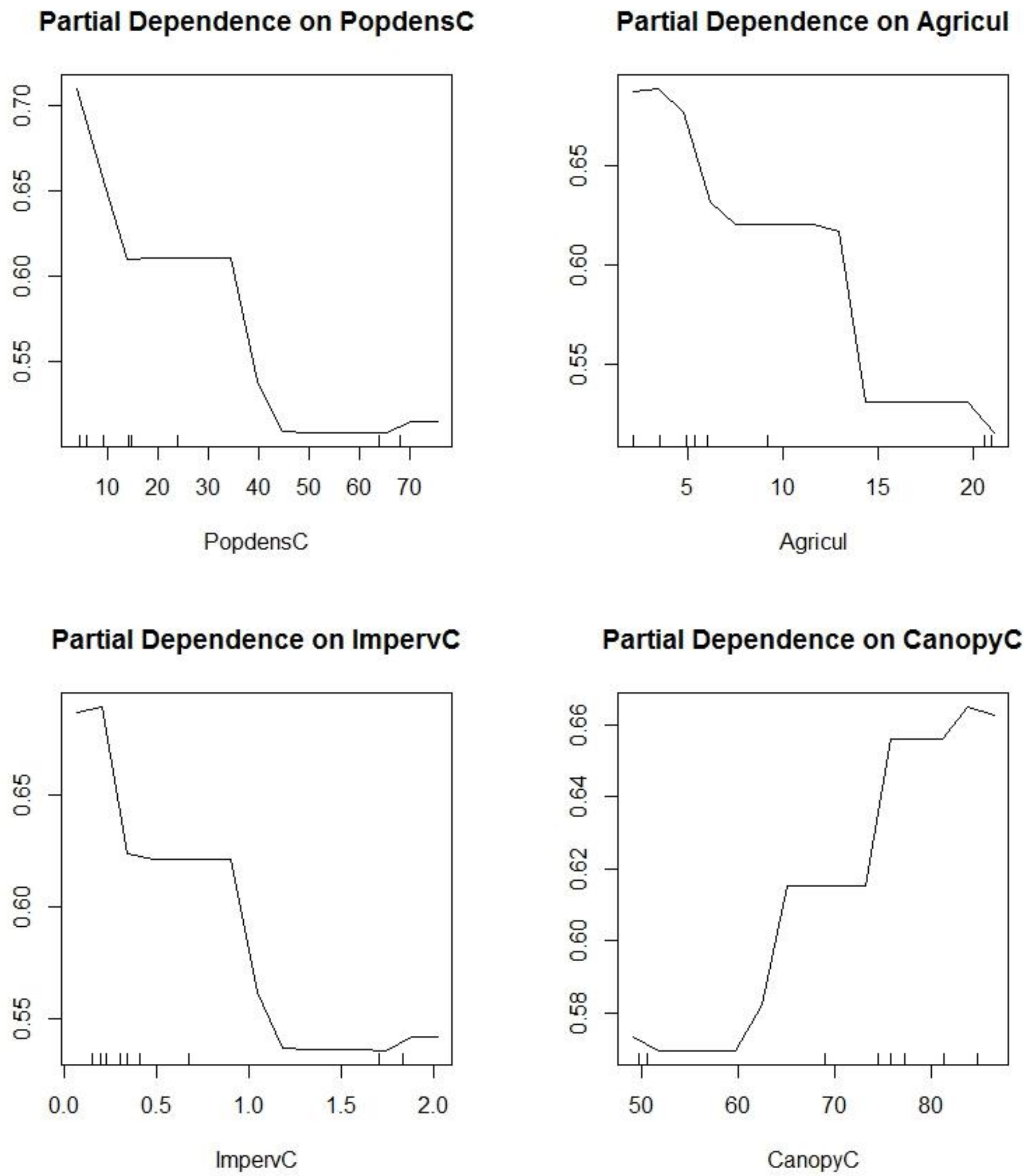

Figure 5. Partial dependence plots from random forest analysis show functional relationships of response variable proportion of pure Bartram's Bass (y axis) with anthopogenic disturbance predictors (x axis). Shown are human population density (PopdensC; no./km^2), percent agricultural land use (Agricul), percent impervious surface (ImpervC), and percent forested riparian canopy cover (CanopyC).

Discussion

Our objective in assay development was to, using hydrolysis probe technology, develop and characterize single-copy nuclear gene assays for three loci that differentiate the black bass species present in South Carolina, Bartram's Bass, Alabama Bass and their hybrids, as well as Smallmouth and Largemouth Bass. However, hydrolysis probe development for the ITS locus was unsuccessful. The ITS locus in the black basses that we have characterized by sequence analysis is GC rich and, despite consultation with several design and synthesis companies, extremely difficult to optimize. GC rich templates have high melting temperatures. Small differences in melting temperatures that characterize species-specific mismatches (the basis of probe differentiation) are slight relative to the melting temperature that is characteristic of species pairs of ITS targets. Because of this, optimizing reaction conditions using standard DNA templates was difficult. This complicated and delayed implementation of ITS probes that were designed. However, our University of South Carolina partners' efforts in identifying and continuing to work through these difficulties resulted in the successful implementation of an alternative ITS probe. The successful development of probes for all three loci is valuable to this and future survey and research work aimed at conservation of Bartram's Bass, as it allows for faster and more economical genetic analysis of samples critical to decision making.

Genetic baseline generation work allowed us to identify tributary streams that, thus far, appear to harbor pure populations of Bartram's Bass. No hybrids were collected from Stevens Creek in South Carolina. In the Chattooga River and Chauga River we have established baselines as to the upstream extent of Alabama Bass/hybrid incursion, and in the Broad River basin in Georgia we have documented that hybrids are present in the shoals near Lake Russel, but appear absent from sites further upstream. These are all important developments for conservation work aimed at this species, as monitoring can be used to track changes that may be associated with time or with conservation actions.

In addition to the value that our genetic baselines provide to future work, our results from Chauga River at Chau-Ram Park may give perspective to previous Chauga River results. In 2004 all of 28 bass collected from Chau-Ram Park were genetically pure Bartram's Bass. When we returned in 2010 our sampling results indicated an upstream incursion of Alabama Bass alleles was underway, as 9 of 17 bass collected, or 53%, were either Alabama Bass or their hybrid with Bartram's Bass. In 2013 however the proportion of hybrid bass collected was lower ($\alpha = .05$). One of 21 fish from the site, or 5%, were hybrids. Additionally, no hybrids have been collected from Chauga River sites upstream from this point. Our partners at University of South Carolina investigated the hypothesis that periods of high discharge in high gradient streams may flush some Alabama Bass and their hybrids from occupied habitats and move them downstream. They found a significant drop in the proportion of hybrids collected from Little River in 2016, compared to the 2014 results reported here (J. Quattro, personal communication). This was after a period of very high water in 2015. Further study is required to confirm a link between changes in hydrology and changes in hybrid proportions in these streams. Current data does provide guarded optimism though, as it may be indicative of a potential for natural mechanisms – hydrologic, biological, or otherwise - to deter an unchecked upstream push of non-native alleles in certain systems.

In consideration of the potential for physical barriers to deter upstream movement of non-native alleles we sampled both below and above Easley Central Dam on Twelvemile Creek. Prior to this the dam was considered a potential barrier to upstream movement of Alabama Bass and their hybrids from Lake Hartwell. However, our sampling showed hybrids were present both below (60%

of black bass collected) and above (65 – 100%) the structure. The mode of transport of Alabama Bass alleles to waters above the dam is not known. It may be that fish were transported and subsequently released upstream by anglers. It's also possible fish traversed the dam during periods of high water. No matter the mechanism of movement, the presence of a high proportion of hybrids above the dam eliminates any assumption that the Easley Central Dam's structure can serve as a barrier to upstream transport of Alabama Bass alleles.

Our finding of hybrids at varying proportions throughout the Little River and Twelvemile Creek sampling areas is in contrast to the pattern of hybrid dispersal apparent from our results on Chattooga and Chauga Rivers, revealing that not all tributary black bass communities in the basin can be expected to have an equal response to the presence of non-natives. Our finding that proportions of pure Bartram's Bass collected was related to both spatial (i.e., distance from impoundment) and anthropogenic factors (e.g., catchment disturbance) suggests testable hypotheses concerning habitat disturbances and effects on Bartram's Bass populations. There is potential that degraded areas lead to fish stress that could affect spawning cues, or that disturbed habitats are more suitable for hybrids than for the endemic bass.

The random forest output plots reveal nonlinear relationships suggesting thresholds in responses. Catchments with human population densities below 45 per km^2 were more likely to support pure Bartram's Bass than those with higher densities. Agricultural land use below 25% of the catchment was more likely to support pure Bartram's Bass. Impervious surface only at very low levels, below 1 to 2%, was more likely to support pure Bartram's Bass. Finally, the plot of riparian canopy cover suggests that at least 80% coverage would be a desirable level to promote and protect habitat for Bartram's Bass. An expansion of this work to include a random sampling element that will further refine our ability to predict habitats and stream systems most likely to support pure Bartram's Bass populations will prove valuable and was initiated in 2017.

Recommendations

The work reported on here represents a completed study funded jointly by USFWS and Sport Fish Restoration. Options for publication in the scientific literature should be considered, a publication draft prepared and submitted. We recommend continued work on Bartram's Bass, including research and survey work currently supported by SARP and Sport Fish Restoration. The Freshwater Fisheries Section should identify internal priorities with respect to the conservation of Bartram's Bass and the control and or promotion of other non-native *Micropterus* species. Once this is done, a Bartram's Bass working group to include colleagues outside of the agency should be convened. This will help to both promote and coordinate collective efforts across various entities in the conservation of this fish unique to South Carolina and Georgia waters. Efforts to educate the public about the dangers of releasing non-natives, and the value of native resources including Bartram's Bass should remain a high priority.

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Job Title: Summer Mortality of Striped Bass Occupying the Lower Saluda River

Period Covered July 1, 2016 – June 30, 2017

Summary

In an effort to determine total mortality of Striped Bass *Morone saxatilis* occupying the lower Saluda River during summer we initiated a telemetry study during 2016. Forty-eight (48) Striped Bass were implanted with acoustic transmitters during May and June 2016 and their movements and fate monitored with an acoustic receiver array and bimonthly manual tracking between May 5, 2016 and December 12, 2016. Total mortality (A) of legal-sized Striped Bass was 39%, fishing mortality (u) was 33%, and natural mortality (v) was 5% between May 1 and September 31, 2016. The low natural mortality rate, which would include catch-and-release mortality, indicated that catch-and-release mortality was not a major source of mortality for Striped Bass summering in the lower Saluda River; however, fishing mortality was high even though harvest was prohibited during four months (June – September) of the five month study. Striped Bass utilized the entire lower Saluda River, but the upper section of the river, especially the area directly below the Lake Murray dam, was the most frequently occupied area. Some Striped Bass demonstrated diurnal movement patterns occupying one segment of the river during the day and a different segment during night.

Introduction

The Santee-Cooper system supports a naturally reproducing Striped Bass population that was overfished during the 1990's and early 2000's. The population is recovering due to more restrictive fishing regulations that include a 26" minimum length limit, a three fish creel, and a summer moratorium on fishing in the lakes to reduce catch and release (C&R) mortality. During summer nearly 50% of the Santee-Cooper spawning stock resides in the lower Saluda River, a thermal refuge that experiences intense fishing pressure where C&R fishing is allowed. When the current Striped Bass fishing regulations were enacted it was assumed that C&R mortality in the lower Saluda River would be low due to cool water temperatures throughout the summer; however, C&R and total mortality rates of Striped Bass occupying the lower Saluda River during summer were unknown. During FY17 we continued a study to determine the total mortality of Striped Bass occupying the lower Saluda River during summer.

Materials and Methods

The lower Saluda River is a 16.5 km "tailwater" that flows from hypolimnetic releases at Lake Murray Dam and terminates at its confluence with Broad River forming the Congaree River (Figure 1). During May and June 2016 Striped Bass were collected from the lower Saluda River and surgically implanted with acoustic transmitters. Transmitters measured 53 mm long, 16 mm in diameter, and weighed 9.5 g (in water) (Model CTT-82-2; Sonotronics, Tucson, Arizona). Each transmitter operated on a single frequency between 69 and 83 KHz and had an advertised battery life of 14 months. An attempt was made to distribute transmitter-implanted Striped Bass evenly among three sections of the river as it was expected that angler effort, and perhaps harvest, varied among sections due to the quality and quantity of angler access. Those sections were: 1) 0.7 km below Lake Murray Dam to Corley Island ("Upper", 4.4 km), 2) Corley Island to I-26 ("Middle", 7.7 km), and 3) I-26 to the confluence of the Saluda and Broad Rivers ("Lower", 4.5 km) (Figure 1). The 0.7 km reach of the Saluda River directly below Lake Murray Dam is not accessible to the public and effectively makes this section a refuge for Striped Bass from the angling public. Current fishing regulations allow for the harvest of Striped Bass from October 1st through May 31st; fish implanted with transmitters during May were vulnerable to legal harvest for up to three weeks, but those implanted during June were not.

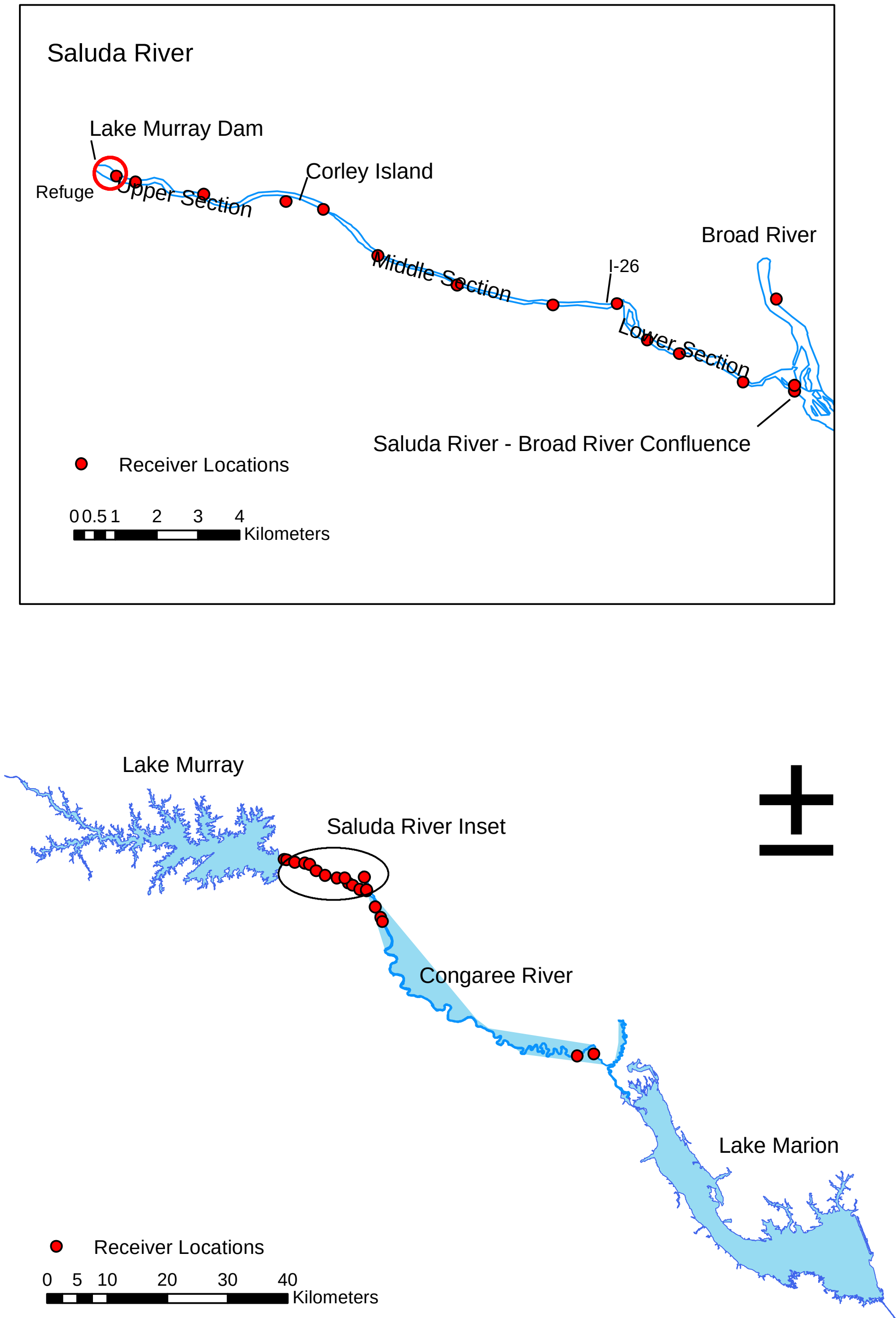

Figure 1. Sections of the Saluda River where Striped Bass were captured and implanted with acoustic transmitters and acoustic receiver locations used to monitor Striped Bass movements during summer 2016.

All Striped Bass were collected with boat-mounted electrofishing equipment. When captured Striped Bass were immediately placed in a foam-lined cooler filled with river water, covered in wet towels, and measured (mm TL [Total Length]). Transmitters were inserted through a 40-mm incision posterior to the right ventral fin. Incisions were closed with three interrupted absorbable sutures (2-0 Maxon; Tyco Health Care). No chemical anesthesia was used; fish were sufficiently immobilized from electrofishing for the short (3-4 minute) implantation procedure. After transmitter implantation fish were immediately released near their capture location. All surgical tools and transmitters were disinfected with Benz-All® (Xttrium Laboratories, Chicago, IL) and then rinsed with simple saline before surgery.

An array of remote acoustic receivers (SUR-3BT, Sonotronics Inc.) was used to collect movement data from transmitter-implanted fish and to assess their emigration from the lower Saluda River (Figure 1). Fourteen (14) receivers were placed in the lower Saluda River to monitor movements within the river, five receivers were placed in the Congaree River, and one receiver was placed in the Broad River to assess emigration from the system. Manual tracking of the lower Saluda River, from the Lake Murray Dam to its confluence with the Broad River, using a USR96 manual tracking kit (Sonotronics, Inc) was conducted bi-monthly between May and September and once each month during October and November 2016 to determine the fate of each fish.

We categorized the fate of each fish as: 1) Alive in the lower Saluda River, 2) Emigrated from the lower Saluda River, 3) Died within the lower Saluda River, 4) Missing from the lower Saluda River, or 5) Harvested. Fish were considered alive if they were actively moving between receiver stations, or moved while manual tracking. Fish that exited the lower Saluda River and were detected at one or more of the stations in the Congaree River were categorized as “emigrated”. Fish were categorized as “dead” when they did not move between receiver locations and were consistently manually tracked in the same location. Fish were categorized as "missing" when they were no longer detected at receiver stations and were not detected in manual searches. "Missing" fish were ultimately lost from the fishery either by angler harvest or natural mortality that resulted in their carcass (transmitter) being removed from the river, and ultimately assumed to have been harvested. "Harvested" fish were those that were reported by anglers as harvested. We made no attempt to advise anglers of the ongoing telemetry study; transmitter-implanted fish did not receive an external tag nor was the study published to the public.

Striped Bass mortality during the summer was estimated using a Kaplan-Meier method adapted for use within a Bayesian framework using Open Bugs software. The model was initiated with uninformative Ln-scale priors to estimate instantaneous fishing (F), natural (M) and total (Z) mortality rates during each two week period between May 1st and September 31st, 2016. To determine the mortality Striped Bass experienced during their use of the Saluda River between May 1 and September 31, 2016 instantaneous rates were summed over the entire study period (FS,MS, and ZS) and converted to seasonal interval rates, with the following equations;

Total Mortality (A) = $1\text{-}e^{-zs}$

Fishing Mortality (u) = (FS*A)/ZS

Natural Mortality (v) = (MS*A)/ZS.

The Kaplan-Meier method accounted for tag loss, primarily due to emigration, during each period. That is, once a fish emigrated, died, or was harvested it was no longer "at risk" and was removed from the "tagged" population in subsequent periods.

To investigate distribution of Striped Bass within the lower Saluda River each receiver was assigned a river km (Rkm) based on its upstream distance (km) from the confluence of the Saluda and Broad rivers (Rkm = 0). The mean daily location of each fish was calculated by averaging the

Rkm of all detections on that date for individual fish. To determine Striped Bass use of each river section (Lower, Middle, Upper, and Refuge) the mean daily location was assigned to the appropriate river section. Only fish that were tracked for at least 30 d between June 10th and September 31st were used to determine the proportion of days individual fish used each section. For a cursory examination of intraday movements mean hourly location (Rkm) was calculated by averaging all detections during each date and hour combination for each fish. Hourly locations were assigned as daylight (08:00 – 19:00) or nighttime (20:00 – 07:00). Only date/hour combinations with at least three observations were used to assess intraday movements. To assess the timing of emigration we used the two lower most receivers in the Saluda River (Figure 1), once a fish passed those receivers it was categorized as “emigrated”. To determine the time (d) fish occupied the Congaree River after emigration the date and time of the first detection at the lowermost receiver in the Congaree River was subtracted from the last detection date and time at the lowermost Saluda River receiver.

Results and Discussion

Between May 5 and May 19, 2016, 32 Striped Bass were collected from the lower Saluda River and implanted with transmitters. Nineteen (19) of those fish were ≥ 660 mm TL and vulnerable to harvest during the month of May. Sixteen (16) additional fish were implanted with transmitters between June 1 and June 2, 2016 (Table 1).

Table 1. Number of Striped Bass implanted with acoustic transmitters, number of legal-sized (> 660 mm TL) Striped Bass implanted, and their mean total length (range in parentheses), in three sections of the lower Saluda River during May and June of 2016

Section	**N**	**N > 660 mm TL**	**Mean TL (mm)**
Upper	16	10	682 (603 - 802)
Middle	14	9	690 (608 - 816)
Lower	18	12	730 (600 - 1050)
Total	48	31	702 (600 - 1050)

Manual tracking of transmitter-implanted Striped Bass was conducted on 33 days between May 24, 2016 and December 12, 2016. During manual tracking events 310 detections were made of 45 unique individuals. Most acoustic receivers were deployed during the first week of May 2016; however, the uppermost Saluda receiver, that monitored the “refuge” area, was not deployed until June 7, 2016. Between May 5 and December 15, 2016 more than one million detections of transmitter-implanted Striped Bass were recorded on the receiver array. The mean number of detections per fish was 21,890 (Range 270 – 61,823).

One fish was removed from mortality analysis after it emigrated from the lower Saluda River on May 26, 2016 seven days post-implantation. The remaining 47 Striped Bass were tracked in the lower Saluda River from 2 to 178 d (mean days in Saluda River = 107 d). Eight fish were either reported as harvested (3 fish) or went missing (5 fish) from the lower Saluda River 2 to 90 d post-implantation. Fish that went missing from the lower Saluda River were not detected in manual searches or at downstream receiver locations and were likely removed from the river by harvest. Four fish were removed from the lower section, and 2 fish each were removed from the middle and upper sections. Five of the 8 fish that were harvested or went missing were removed during May.

One fish was removed from the river during each June, July, and August when harvest was prohibited. Seven of the fish that were reported as harvested or went missing were >686 mm TL and were of legal-size. Only one of the harvested or missing fish may have been shorter than the 660 mm TL size limit, that fish was removed on August 9th, 2016 and was 654 mm TL on May 11th, 2016 when it was implanted with a transmitter. Only one fish was assumed to suffer from natural or catch-and-release mortality when it was found immobile 51 d post-implantation. The remaining 38 fish survived in the Saluda River for 45 to 178 d (mean d in Saluda River = 128) until they emigrated.

Mortality was estimated for two groups of Striped Bass, one model included all Striped Bass (N=47) and the second model included only those (N = 31) that were ≥ 660 mm TL (legal-sized) at the time of transmitter-implantation. The mean number of fish “at risk” each period for all fish was 34 (Range; 10 – 42 fish) and the mean number of legal-sized fish “at risk” each period was 22 (range 7 – 26 fish). Total mortality (A) between May and September, 2016 for all Striped Bass was 32% and total mortality for legal-sized Striped Bass was 39% (Table 2). Natural mortality (v) was low (5%) for both groups; however, fishing mortality (u) was high (25% and 33%, for the two groups) during the five month period, especially considering that harvest was only allowed during May. It appears that natural mortality, which would include catch-and-release mortality, is not a problem for the Striped Bass population summering in the lower Saluda River; however, extending the fishing season beyond May could result in unacceptable rates of fishing mortality.

Table 2. Median total mortality (A), fishing mortality (u), and natural mortality (v) of two groups of transmitter-implanted Striped Bass between May and September, 2016 in the lower Saluda River, SC. Credible Intervals (2.5% – 97.5%) in parentheses.

	All Striped Bass	**Legal-sized Striped Bass**
A	0.32 (0.17 - 0.51)	0.39 (0.21 - 0.63)
u	0.25 (0.12 - 0.44)	0.33 (0.16 - 0.57)
v	0.05 (0.01 - 0.16)	0.05 (0.00 - 0.18)

Distribution of Striped Bass among river sections, based on mean daily locations, varied throughout the summer. The upper section, which included the refuge area, was the most frequently used section with on average 48% (Range 36% - 58%) of the fish occupying that section between May 11 and September 1, 2016 (Figure 2). Within the upper section the refuge was the most frequently used area with on average 34% (Range; 14% - 54%) of the fish occupying the refuge between June 7 and September 1, 2016 (the refuge was not monitored before June 7, 2016). The lower Section was the least used section with on average 20% (Range; 13% - 30%) of the fish occupying that section. Cursory examination of the distribution data indicated that discharge may influence section use. High flow (> 2,000 cfs) events appeared to redistribute fish downstream while stable flows increased movement into up river sections (Figure 2).

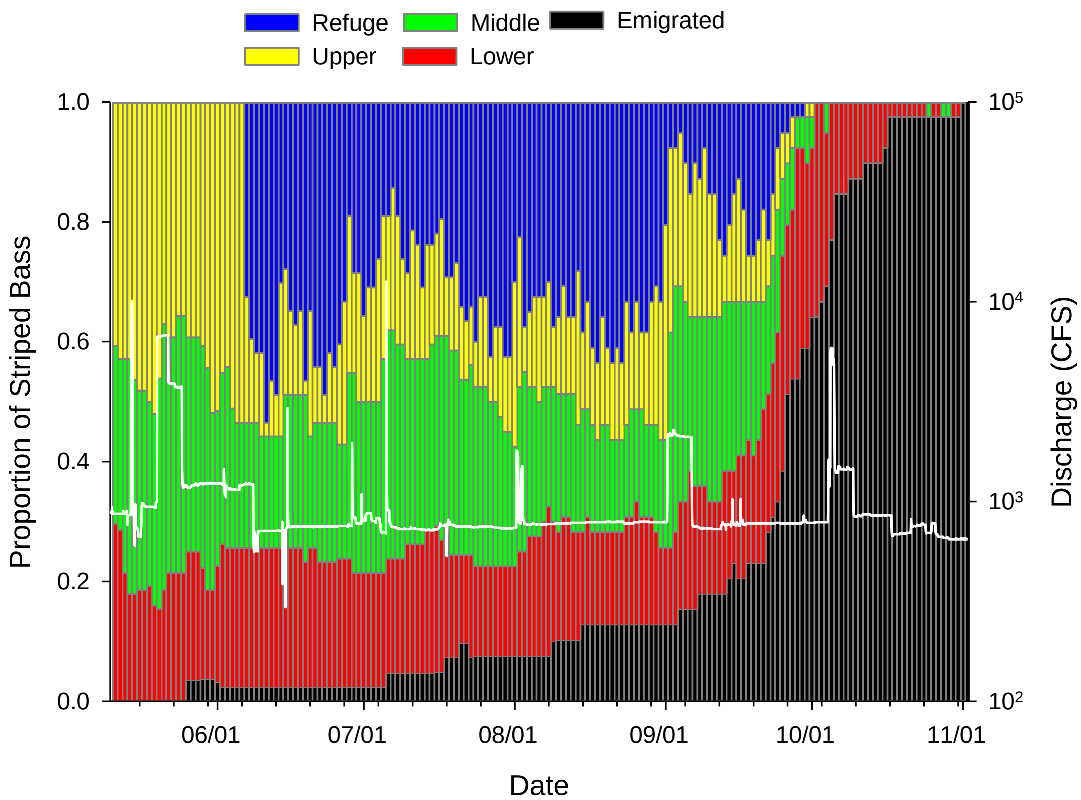

Figure 2. Proportion of transmitter-implanted Striped Bass occupying four sections of the lower Saluda River and river discharge (CFS) on each date during 2016.

Individual Striped Bass spent most of their time in a single river section. Mean daily locations for most (83%) fish occurred within a single river section. Five fish remained in the lower section, never moving above I-26, and four other fish never moved above Corley Island into the upper section. The remaining 31 fish used the entire river including the refuge below Lake Murray Dam. Seventy-seven percent (77%) of those fish used a primary river section with >50% of their mean daily locations within that section. Four fish primarily used the upper section with 53 – 75% of their mean daily locations within that section. Eleven fish primarily used the refuge with 50 –

91% of their mean daily locations within that section. Seven fish primarily used the middle section with 54 – 93% of their mean daily locations within that section. Eight fish primarily used the lower section with 69 – 100% of their mean daily locations within that section. The refuge below Lake Murray dam was the most heavily used section for fish that utilized the entire river, 42% of all mean daily locations were within that 0.7 km section. The next most heavily used section was section 2 with 24% of the mean daily locations.

Although intraday movements were not evaluated for all fish it was clear that some fish chose to occupy different river segments during the day and night. Those movements were especially apparent in the upper section where fish were more frequently located within the refuge during the day and often moved below the refuge at night. Mean hourly locations (N = 13,340) for 14 fish that primarily used the upper section were calculated. Sixty-four percent (64%) of locations at Receiver 1 (Rkm 16.2, within the refuge) were during daylight hours while 79% of the locations at Receiver 2 (Rkm 15.8, below the refuge) were during nighttime hours (Figure 3). Fish #61 exemplified this diurnal movement between June 22 and June 27, 2016 inhabiting the refuge during the day and moving below the refuge at night, while fish #63 occupied the refuge both day and night, only moving below the refuge during a long distance migration (Figure 4). Diurnal movements were not restricted to the refuge area; fish #97 in a downstream section also inhabited different river segments during the day and night (Figure 4). The proportion of fish that exhibited diurnal movements is currently unknown; however, that information may be useful for determining the vulnerability of fish that primarily inhabited the refuge to harvest.

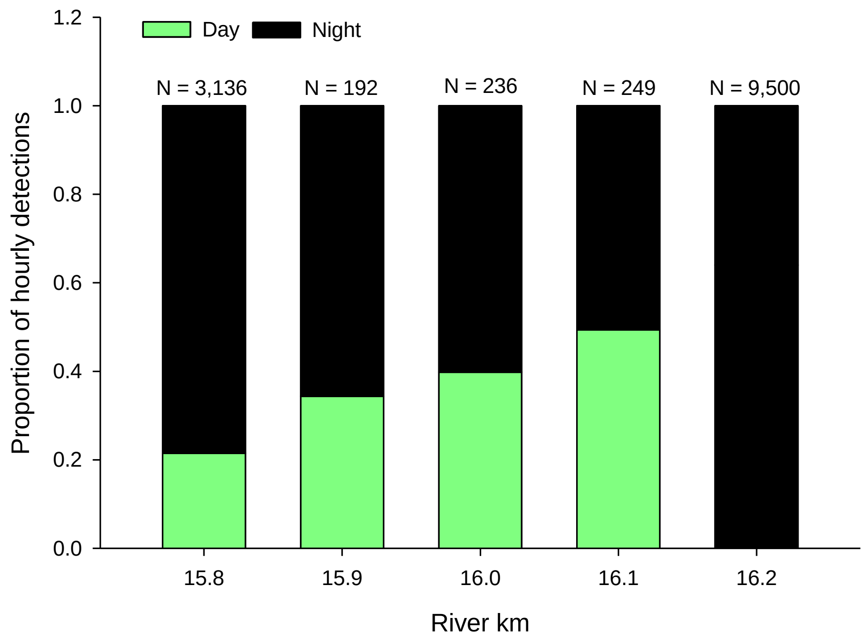

Figure 3. Proportion of transmitter-implanted Striped Bass mean hourly locations by day period and river km in the upper section the Saluda River between May and September 2016. Striped Bass above river km 16.0 were within the refuge area.

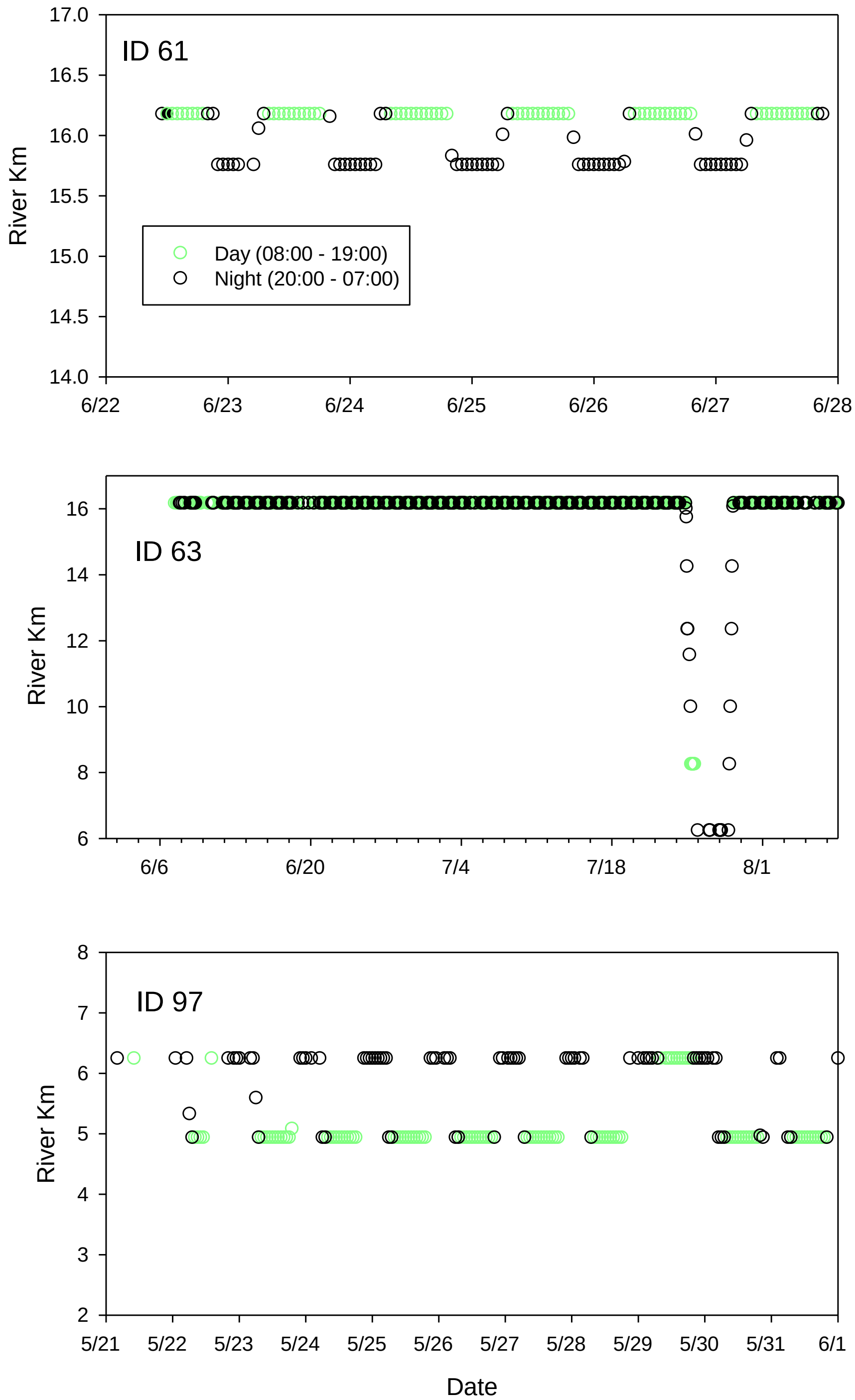

Figure 4. Diurnal movements of three transmitter-implanted Striped Bass, based on mean hourly locations (River km), in the lower Saluda River during summer 2016.

Striped Bass emigrated from the Saluda River between May 26, 2016 and October 30, 2016 (Figure 5). The median (and mode) date of emigration was September 25, 2016 when 5 Striped Bass emigrated from the lower Saluda into the Congaree River. Most (29 of 39) fish emigrated between September 21, 2016 and October 16, 2016. One fish emigrated from the lower Saluda River on May 26, 2016 seven days post-implantation, and was detected 80 km downstream in the Congaree River 1.3 d after exiting the Saluda River. That fish's transmitter was recovered from the Cooper River by a scuba diver during August and likely suffered from tagging related mortality. Striped Bass that emigrated before September were ≤ 653 mm TL (mean TL = 636 mm), while those that emigrated after September were 603 mm – 988 mm TL (mean TL = 701 mm). Only one fish that emigrated from the lower Saluda into the Congaree River returned to the lower Saluda River. That fish moved into the upper Congaree and returned to the lower Saluda River on three occasions during summer 2016 before emigrating. The mean number of d Striped Bass occupied the Congaree River after exiting the Saluda River was 10.25 (Range; 0.81 – 36.02 d).

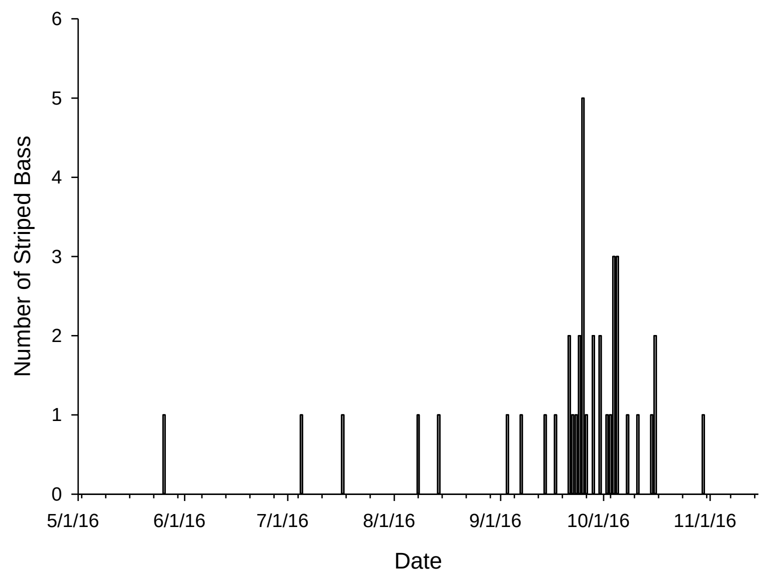

Figure 5. Number of transmitter-implanted Striped Bass emigrating from the lower Saluda River on each date between May 1, 2016 and November 1, 2016.

Recommendations

1. Complete final report.

Prepared By: Jason Bettinger Title: Wildlife Biologist

Job Title: Determining Fishery Enhancement Potential in Stevens Creek Reservoir

Period Covered July 1, 2016 – June 30, 2017

Summary

Four half-mile shoreline transects in Stevens Creek reservoir were sampled with boat electrofishing during fall of 2016. Twenty-seven (27) fish species were collected. Relative abundance was greatest for Coastal Shiner *Notropis petersoni* (42%) and Bluegill *Lepomis macrochirus* (19%), the relative abundance of all other species was < 7%. Otoliths (N = 282) were collected to estimate age structure and growth of selected sportfish species, including Largemouth Bass *Micropterus salmoides*, Chain Pickerel *Esox niger*, Black Crappie *Pomoxis nigromaculatus*, Bluegill, Redbreast Sunfish *Lepomis auritis*, Redear Sunfish *Lepomis microlophus*, and Yellow Perch *Perca flavescens*. Between February and May 2017, 21 Striped Bass *Morone saxatilis* and 17 Striped Bass X White Bass Hybrid *Morone saxatilis X Morone chrysops* were implanted with acoustic transmitters and monitored with an array of 15 acoustic receivers. Individuals of both species used the entire reservoir during 2017. Two Hybrid Striped Bass emigrated from the reservoir and were detected alive below Stevens Creek dam. A total of 96 Largemouth Bass were implanted with radio transmitters during fall 2016 and spring 2017 and tracked monthly from January 2017 to July 2017 to estimate total mortality and exploitation. Four of the 56 Largemouth Bass implanted during fall 2016 were harvested and four others were caught and released by anglers. Annual mortality of Largemouth Bass has not yet been estimated.

Introduction

Recent increases in dissolved oxygen concentrations from releases at J. Strom Thurmond Dam have improved fishery habitat in Stevens Creek reservoir. Stevens Creek reservoir has received minimal study since the improved dissolved oxygen conditions. During FY17 a comprehensive 2-year assessment of the fisheries resources was initiated with the following objectives: 1) Determine the abundance of chlorophyll a, 2) Quantify the abundance and speciation of pelagic forage fishes in the mainstem of the Savannah River, 3) Determine the relative abundance, condition and growth of key sportfish species, 4) Document the seasonal movements, emigration, and temperature use of Striped Bass and Hybrid Striped Bass, and 5) Estimate the exploitation of Largemouth Bass, the most sought after species in the reservoir. During FY 2017 significant progress was made on several of those objectives.

Materials and Methods

Shoreline sampling with boat-mounted electrofishing was conducted at four 0.5-mile sections distributed along the length of the reservoir between Stevens Creek Dam and J. Strom Thurmond Dam (Figure 1). A fifth site (Site 5) in Stevens Creek proper will be sampled during September and October of 2017. All collected sportfish were measured (TL, mm) and weighed (g); nongame species were enumerated. To evaluate age structure and estimate growth of sportfish species otoliths were removed from Largemouth Bass, Yellow Perch, Redear Sunfish, Bluegill, and Redbreast Sunfish. Otoliths were removed from up to 5 individuals > 75 mm TL of each species in each section (tailwater [sites 1 and 2] and reservoir [sites 3 and 4]) from predetermined length groups. Up to 5 Chain Pickerel in each length group from each section were retained and frozen. Frozen Chain Pickerel were transferred to Coastal Carolina University for age processing in Dr. Derek Crane's lab.

Dr. Crane estimated the age of Chain Pickerel and evaluated the precision of age estimation using sectioned pelvic, pectoral, dorsal, and anal fin rays, scales, cleithra (both sectioned and whole), and otoliths.

Between February 23 and May 23, 2017 Striped Bass and Hybrid Striped Bass were collected with boat-mounted electrofishing equipment from J. Strom Thurmond Tailwater, Stevens Creek Reservoir, Stevens Creek, and Stevens Creek Tailwater and surgically implanted with temperature-sensing acoustic transmitters. Transmitters measured 53 mm long, 16 mm in diameter, and weighed 9.5 g (in water) (Model CTT-82-2; Sonotronics, Tucson, Arizona). Each transmitter operated on a single frequency between 69 and 83 KHz and had an advertised battery life of 14 months. When captured Striped Bass were immediately placed in a foam-lined cooler filled with lake water, covered in wet towels, and measured (mm TL [Total Length]). Transmitters were inserted through a 40-mm incision posterior to the right ventral fin. Incisions were closed with three interrupted absorbable sutures (2-0 Maxon; Tyco Health Care). No chemical anesthesia was used; fish were sufficiently immobilized from electrofishing for the short (3-4 minute) implantation procedure. After transmitter implantation fish were immediately released near their capture location. All surgical tools and transmitters were disinfected with Benz-All® (Xttrium Laboratories, Chicago, IL) and then rinsed with simple saline before surgery.

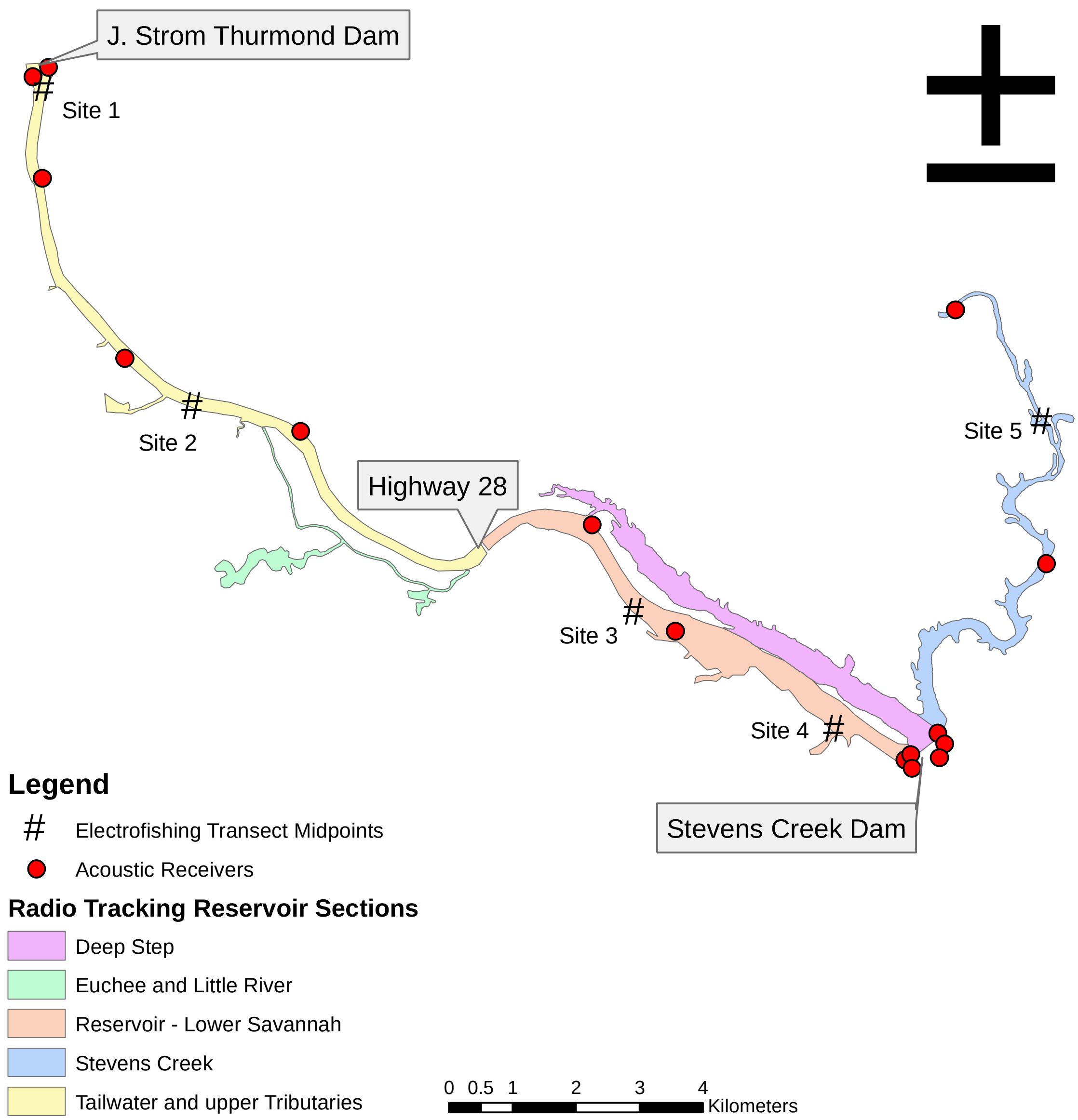

Figure 1. The midpoint of boat electrofishing transects, acoustic receiver locations, and radio tracking sections in Stevens Creek Reservoir, South Carolina – Georgia.

An array of remote acoustic receivers (SUR-3BT, Sonotronics Inc.) was used to collect movement data from transmitter-implanted Striped Bass, assess their emigration from the Stevens Creek Reservoir, and evaluate temperature use (Figure 1). Ten receivers were placed in the Savannah River between J. Strom Thurmond Dam and Stevens Creek Dam, two were placed in Stevens Creek proper, and three were placed below Stevens Creek Dam to assess emigration from the Reservoir. Manual tracking of the Savannah River, from J. Strom Thurmond Dam to Stevens Creek Dam, using a USR96 manual tracking kit (Sonotronics, Inc) was conducted to determine the fate of fish that were not detected on the receiver array.

To determine the exploitation rate of Largemouth Bass a radio telemetry study was initiated during November, 2016. Largemouth Bass were collected with boat-mounted electrofishing equipment from the main Savannah River channel between J. Strom Thurmond Dam and Stevens Creek Dam and surgically implanted with radio transmitters. Transmitters measured 24 mm long, 13 mm wide, weighed 3.6 g and possessed a 198 mm trailing whip antenna (Model F1580; Advanced Telemetry Systems, Isanti, Minnesota). Each transmitter operated on a single frequency between 148.000 and 159.999 MHz and had a warrantied battery life of 220 days. When captured Largemouth Bass were placed in a livewell and held until multiple fish, usually three or four, were collected. Before transmitter implantation each fish was removed and "shocked" with 3 – 4 amps (60 pps) for approximately 4 seconds with the boat-mounted electrofishing system to immobilize them before transmitter implantation. Once immobilized fish were placed in a foam-lined cooler filled with lake water, covered in wet towels, and measured (mm TL [Total Length]). Transmitters were inserted through a 30-mm incision posterior to the right ventral fin. Incisions were closed with two or three interrupted absorbable sutures (3-0 Prolene with an FS-1 reverse cutting needle; Ethicon Inc., Somerville, New Jersey) allowing the antenna to trail from the incision. To facilitate the reporting of harvested and caught and released Largemouth Bass external $50 reward tags were placed in the incision before closing. Reward tags (FM-95W, Floy Tag and Manufacturing, Inc., Seattle, Washington) were internal anchor tags with an 80 mm external streamer that included the tag number and the phrases “Call SCDNR 888-824-2472”, and “Clip for $50 REWARD expires 7/2018”. After transmitter implantation fish were immediately released near their capture location. All surgical tools and transmitters were disinfected with Benz-All® (Xttrium Laboratories, Chicago, IL) and then rinsed with simple saline before surgery.

We attempted to locate transmitter-implanted Largemouth Bass monthly beginning in January 2017. Mobile radio tracking was conducted from boat with an R200 scanning receiver and 5 element Yagi antenna (Advanced Telemetry Systems, Isanti, Minnesota) while traveling 3 – 5 kph. In the lower reservoir, Stevens Creek Dam to Hwy 28, two tracking passes, one on each side of the reservoir were made due to the wide channel width, two passes were also made in the “Deep Step” area, while single passes were made in the main Savannah Channel above Hwy 28, Little River, Euchee Creek, Keokee Creek and Little Keokee Creek (Figure 1). Once detected we estimated the position of each fish using the “0-point” method The “0-point” method simply involves “homing” in on the fish while reducing receiver gain until a strong signal is received with the gain turned down to almost 0. Once located the position of the fish was recorded with a handheld GPS receiver, and time, water temperature and depth were recorded.

Results and Discussion

To determine the abundance of chlorphyll-a, an indicator of primary production, water samples were collected from three sites on May 31, 2017. Those sites were located just below Thurmond Dam (upper site), just above Highway 28 (middle site), and just above Stevens Creek

Dam (lower site) (Figure 1). Water samples were transferred to Swearingen Ecology Associates – United Sates (SEAUS, Inc., Irmo, SC) where they were analyzed for Chorophyll-a. Chlorophyll-a concentration was very low (0.5 or 0.6) at each of the three sites on May 31, 2017.

One 0.5 mile shoreline transect (Site 4) was electrofished on September 27, 2016 and the three other transects were sampled on October 4, 2016. Total electrofishing on time ranged from 35 minutes at Site 1 to one hour at site 4 (mean on time = 44 min). Twenty-seven (27) species of fish were collected during electrofishing surveys (Table 1). Relative abundance was greatest for Coastal Shiner (42% of the fish collected) and Bluegill (19% of the fish collected). Chain Pickerel, Golden Shiner *Notemigonus crysoleucas*, Lrgemouth Bass, and Redear Sunfish were common each representing > 5% of the fish collected. The relative abundance of all other species was < 2.2%. The relative abundance of small-bodied fishes, especially minnows, was grossly underestimated. Not only are small-bodied fish less susceptible to boat electrofishing gear, but often schools of minnows were encountered that were too numerous to effectively capture.

Table 1. Relative abundance (%) and total number of fishes collected from four sites in Stevens Creek Reservoir with boat electrofishing during fall 2016.

Species	Site				Grand Total
	1	2	3	4	
American eel	2.48%	1.01%	0.00%	0.23%	0.57%
Bowfin	0.00%	0.00%	0.32%	0.00%	0.09%
Redfin pickerel	0.00%	0.00%	0.00%	0.47%	0.19%
Chain pickerel	10.74%	3.52%	6.47%	4.20%	5.48%
Whitefin shiner	0.00%	1.01%	0.00%	0.00%	0.19%
Eastern silvery minnow	0.00%	0.00%	2.59%	1.17%	0.57%
Golden shiner	0.00%	0.00%	4.21%	11.66%	5.95%
Spottail shiner	0.00%	0.00%	0.32%	0.70%	0.38%
Coastal shiner	0.00%	14.57%	56.96%	55.94%	42.06%
Creekchub sucker	4.13%	0.00%	0.32%	3.26%	1.89%
Spotted sucker	9.09%	2.51%	0.00%	1.63%	2.17%
Black bullhead	0.00%	0.00%	0.00%	0.23%	0.09%
Yellow bullhead	0.00%	0.50%	0.00%	0.00%	0.09%
Brown bullhead	0.83%	0.50%	0.00%	0.00%	0.19%
Pirate perch	0.83%	2.01%	0.65%	0.70%	0.95%
Mosquito fish	0.00%	0.00%	0.00%	0.23%	0.09%
Flier	0.00%	0.00%	0.00%	0.47%	0.19%
Redbreast sunfish	4.13%	6.53%	0.32%	0.23%	1.89%
Pumpkinseed sunfish	0.00%	0.00%	0.00%	0.23%	0.09%
Warmouth	6.61%	2.51%	1.29%	0.93%	1.98%
Bluegill	39.67%	44.22%	11.33%	7.46%	19.19%
Dollar sunfish	0.00%	0.00%	0.32%	0.00%	0.09%
Redear sunfish	11.57%	7.04%	6.15%	5.59%	6.71%
Largemouth bass	6.61%	9.05%	7.12%	3.73%	6.05%
Black crappie	1.65%	0.00%	0.97%	0.23%	0.57%
Yellow perch	1.65%	1.51%	0.65%	0.23%	0.76%
Blackbanded darter	0.00%	3.52%	0.00%	0.47%	0.85%
Total Fish	121	199	309	429	1058

During 2016 otoliths were collected from 6 Black Crappie, 60 Bluegill, 74 Largemouth Bass, 23 Redbreast Sunfish, 49 Redear Sunfish and 25 Yellow Perch to estimate growth and describe age structure of selected sportfish species. Ages were estimated for all collected otoliths by two independent "readers"; however, reader agreement was poor (< 57%). Due to poor reader agreement all otoliths were thin sectioned during 2017 to improve readability; however, the ages of those structures have not been estimated. Dr. Derek Crane and his students at Coastal Carolina University evaluated the precision of Chain Pickerel age estimates from sectioned pelvic, pectoral, dorsal, and anal fin rays, scales, cleithra, and otoliths. Otoliths were the most precise structure, and their use was recommended for age estimation of Chain Pickerel collected from Stevens Creek Reservoir. Forty-five (45) Chain Pickerel collected from Stevens Creek Reservoir were aged using sectioned otoliths. Those fish ranged from Age 0 to Age VI (Table 2). While otoliths were the most precise structure there were difficulties identifying the first annulus due to an opaque core, as such some fish may be under-aged by one year.

Table 2. Mean length at age, standard error in parentheses, and number of otoliths examined for 45 chain pickerel collected from Stevens Creek Reservoir during fall 2016 and aged using sectioned otoliths.

Age	**Mean TL (mm)**	**N**
0	129 (6.2)	8
1	154 (12.0)	9
2	270 (18.0)	15
3	414 (17.2)	5
4	505 (33.4)	4
5	514 (25.8)	3
6	545	1

On 18 days between February 23, 2017 and May 23, 2017 we attempted to capture and implant Striped Bass with acoustic transmitters. Due to difficulties capturing sufficient numbers of Striped Bass from Stevens Creek Reservoir Hybrid Striped Bass were also implanted with acoustic transmitters to provide a potential surrogate for evaluating emigration from the reservoir. Twenty-one (21) Striped Bass (Mean TL = 837 mm; Range 614 – 1083 mm TL) and 17 Hybrid Striped Bass (Mean TL = 635 mm; Range 535 – 710 mm TL) were captured and implanted with acoustic transmitters. Eighteen (18) Striped Bass and 13 Hybrid Striped Bass were captured from within 200 m of the J. Strom Thurmond Dam, most of which were above the safety buoy line. One Striped Bass each was collected from the Savannah River channel just upstream of Hwy 28, Stevens Creek proper, and below the Stevens Creek Dam and then transferred to Stevens Creek Reservoir. Between March 28, 2017 and April 4, 2017 four Hybrid Striped Bass were captured from Keokee Creek and implanted with transmitters. Significant effort was expended in other parts of the system, especially in Stevens Creek proper; however, very few Striped Bass or Hybrid Striped Bass were encountered in those areas.

Between February 28, 2017 and October 24, 2017 there were nearly 2 million Striped Bass or Hybrid Striped Bass detections on the acoustic receiver array. The mean number of detections for individual fish was 51,751 (Range, 228 – 104,764). Manual tracking of the Savannah River channel to locate missing fish was conducted once during each September and October 2017 during which 22 fish were located.

Sixteen of 21 Striped Bass were alive through October 2017. Four Striped Bass went missing between May and August, 2017, and one Striped Bass was harvested during September, 2017. Nine of 17 Hybrid Striped Bass were alive during October. Four Hybrid Striped Bass are currently missing, two appear to have died, and two fish emigrated from the reservoir and were alive during

October, 2017 below Stevens Creek dam. Preliminary movement data, based on mean daily locations of individual fish, indicated that Striped Bass utilized most of the reservoir between March and October 2017; however, the majority (71%) of the mean daily locations were within 1 km of the J. Strom Thurmond Dam (Figure 2). Seventeen of the 21 Striped Bass traversed the entire Savannah River channel from Stevens Creek Dam (Rkm = 0) to J. Strom Thurmond Dam (Rkm = 20) at some point between March and October, 2017. Similar distribution of Hybrid Striped Bass was observed with 63% of their mean daily locations within 1 km of J. Strom Thurmond Dam (Figure 3). Fourteen of 17 Hybrid Striped Bass utilized the entire Savannah River channel, and two of those fish emigrated below Stevens Creek Dam. Three Striped Bass and two Hybrid Striped Bass also moved up Stevens Creek proper at least 4.5 km, and one of those Striped Bass moved at least 10.3 km up Stevens Creek proper.

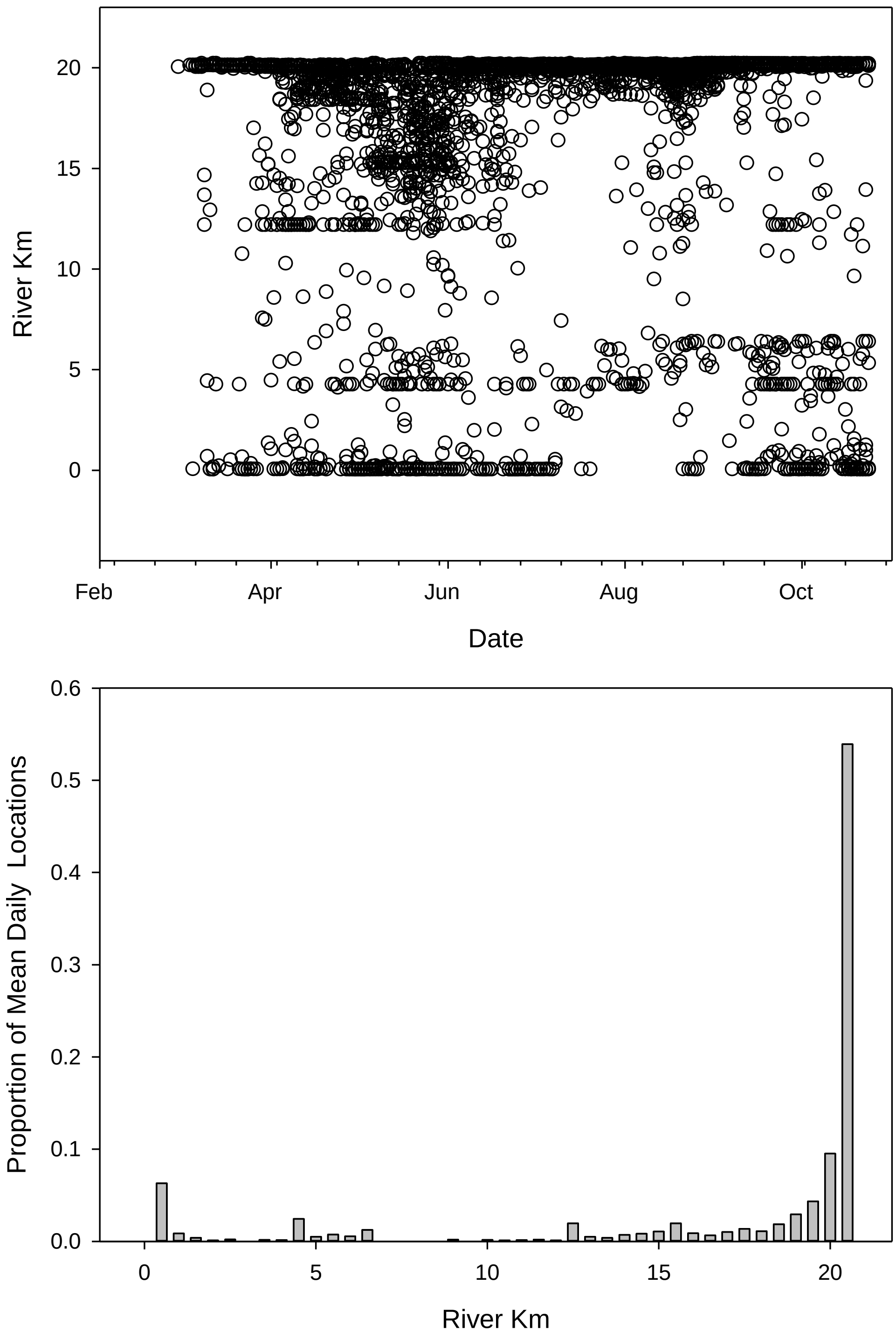

Figure 2. Mean daily locations by river kilometer of transmitter-implanted Striped Bass in Stevens Creek Reservoir between March and October 2017 (top panel) and proportion of Striped Bass mean daily locations (n = 3,615) by river kilometer (bottom panel). Stevens Creek Dam is located at River km-0.0 and J. Strom Thurmond Dam is located at river km-20.7.

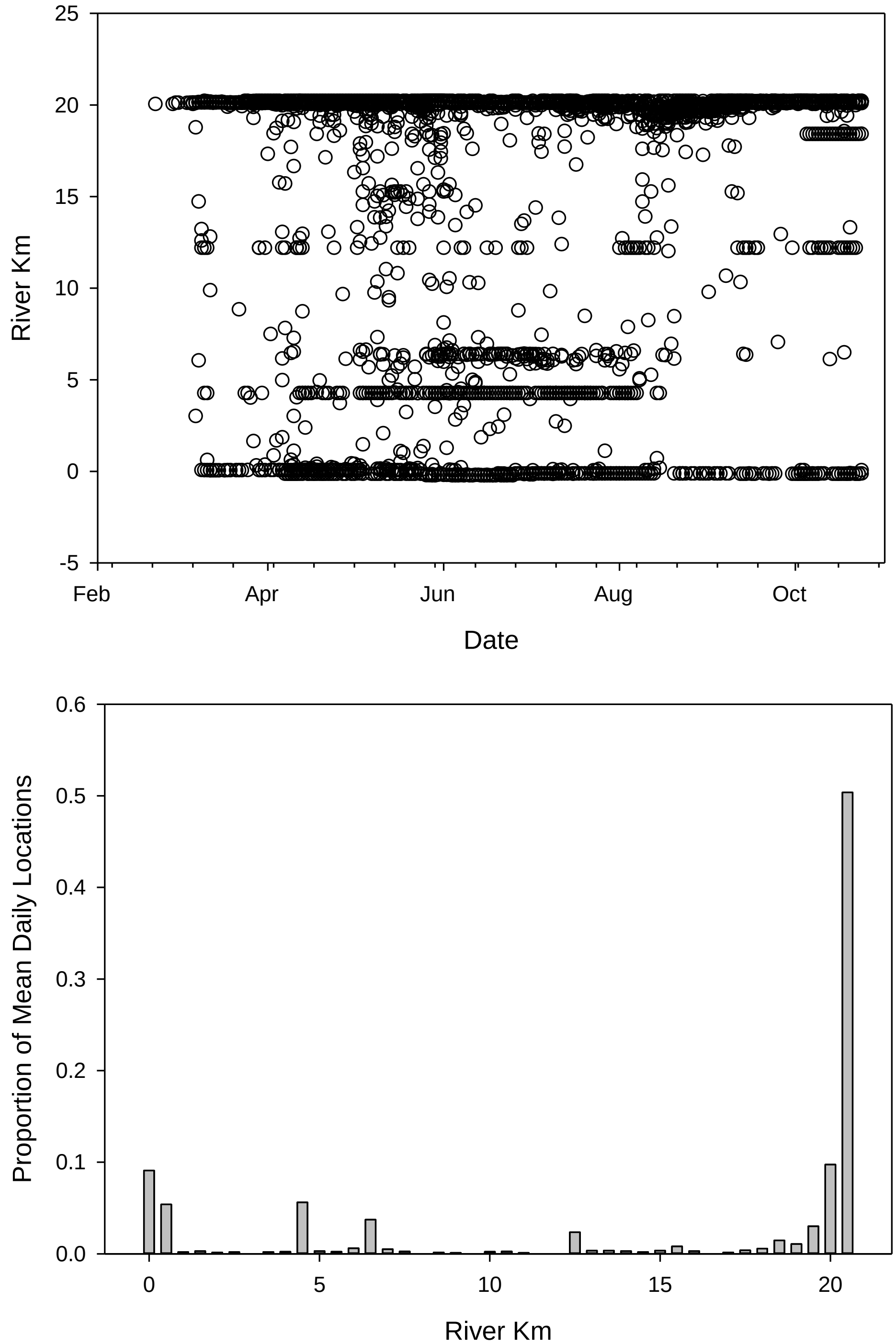

Figure 3. Mean daily locations by river kilometer of transmitter-implanted Hybrid Striped Bass in Stevens Creek Reservoir between March and October 2017 (top panel) and proportion of Hybrid Striped Bass mean daily locations (n = 2,597) by river kilometer (bottom panel). Stevens Creek Dam is located at River km-0.0 and J. Strom Thurmond Dam is located at river km-20.7.

Fifty-six (56) Largemouth Bass (mean TL = 392 mm; Range 306 – 611 mm TL) were captured from Stevens Creek Reservoir and implanted with radio transmitters and $50 reward tags between November 3, 2016 and November 16, 2016. An additional 40 Largemouth Bass (mean TL = 414; Range 314 – 556 mm) were implanted with radio transmitters and reward tags between May 16, 2017 and June 22, 2017.

We attempted to locate Largemouth Bass implanted during November 2016 once each month between January and June 2017. Largemouth Bass implanted during May and June 2017 were located once each month beginning July 2017, and we will continue to track them through February 2018. There were a total of 56 tracking dates during the study period with on average 5 tracking dates per month. Each month the entire Savannah River channel, all accessible coves and creek mouths, as well as the area known as "Deep Step" were tracked. Stevens Creek proper was tracked on two occasions, but no fish were detected. During the tracking evets 341 locations of 90 individuals were collected. Detection probability (number at large/number detected) during the first five monthly tracking events (January – May, 2017) was poor (<52%). Modifications to the tracking methods, primarily removing transmitter frequencies from the frequencies scanned once they were detected, were made during June which resulted in much higher (> 90%) detection probabilities.

Of the 56 Largemouth Bass implanted during 2016, 32 were alive through June 2017 when tracking of those fish ceased. Four fish were harvested by anglers between January and April 2017 and four additional fish were reported as caught and released between January and July 2017. Nine fish died between 0 and 216 days post-tagging. The fate of the 11 remaining fish has not yet been determined. Of the 40 fish implanted during May and June 2017, 32 are currently alive, six fish died and the fate of two fish is unknown. Mortality, including exploitation, of Largemouth Bass based on the transmitter-implanted fish has not yet been estimated.

The abundance and speciation of pelagic forage fishes was not estimated during 2016. Hydroacoustic sampling and associated gill netting was planned for the spring and summer of 2017; however, delays in procurement and outfitting of a new hydroacoustic vessel resulted in rescheduling that effort to 2018. In preparation for hydroacoustic sampling bathymetric data was collected with a Lowrance Elite 7 TI, and a bathymetric map created using ReefMaster software. Those data will be used to identify the deepest channel along Savannah River channel for hydroacoustic data collection (Figure 4). At project completion the bathymetry data will be available for viewing in Google Earth (kmz file) and for loading onto recreational chart plotters.

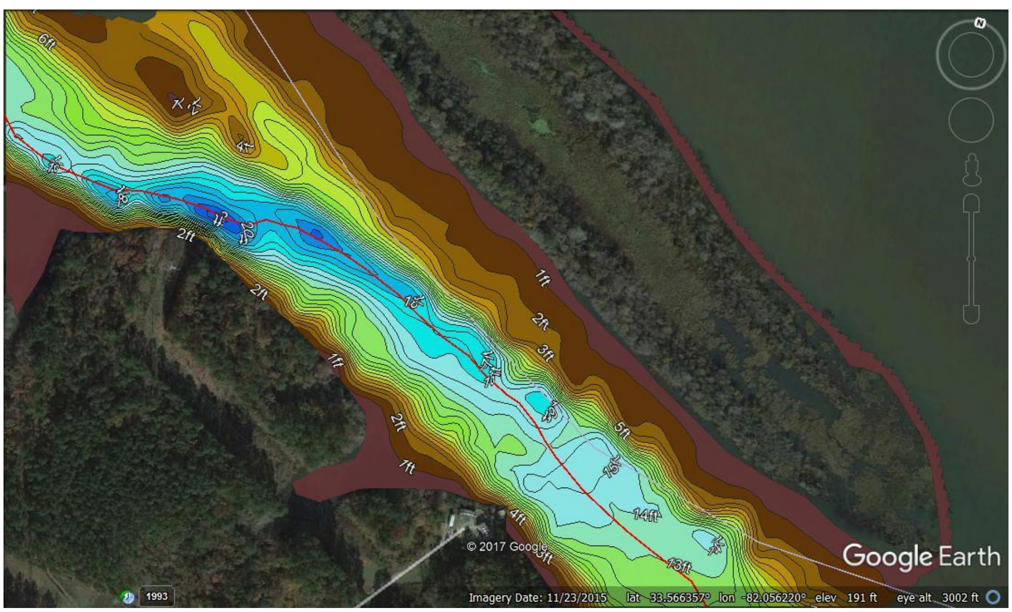

Figure 4. Preliminary depth contours in lower Stevens Creek Reservoir developed from bathymetry data collected during spring and summer 2017.

Recommendations

We were unable to quantify the abundance and speciation of pelagic forage fishes during 2016 due to delays in equipment delivery and fabrication. During fall 2017 the hydroacoustic vessel was completed. Hydroacoustic data collection and associated gillnetting is planned for spring and summer 2018 to quantify the abundance and speciation of pelagic forage fishes in Stevens Creek Reservoir. A no cost extension through March, 2019 was requested to allow for data analysis and report completion.

Other aspects of the project will continue as planned. Shoreline electrofishing will be conducted during October of 2017. Selected sportfish collected during 2016 and 2017 will be aged using sectioned otoliths to estimate growth and age structure. Transmitter-implanted Striped Bass and Hybrid Striped Bass will be monitored with the acoustic receiver array through June 2018. Radio-implanted Largemouth Bass will be monitored through June 2018 with monthly manual tracking of the reservoir and their mortality estimated using a known-fate model.

Prepared By: Jason Bettinger Title: Wildlife Biologist

Job Title: Fish Community Response to Dam Removal in Twelvemile Creek, Pickens County, South Carolina

Period Covered July 1, 2016 – June 30, 2017

Summary

Dam removal is considered an effective tool for restoring ecological integrity to rivers and streams, yet few studies have investigated the effects and recovery dynamics of aquatic communities after dam removal(s), and virtually no published research has emerged from dam removals in the southeastern U.S. This study examines the effects of multiple dam removals on the aquatic habitats and biota of Twelvemile Creek, Pickens County, South Carolina.

We collected biological and habitat data above and below two removed dams, and from upstream and downstream reference sites, for an approximate timeframe of 5-years prior and 5-years following dam removals. We evaluated ecological effects and recovery by examining changes in habitat (depth, flow, substrate), biological community metrics (fish and aquatic macroinvertebrates), and community structure over the study period.

The bulk of instream habitat changes occurred within one year of each dam removal; major geomorphic adjustments led to dramatically increased flow rates and shifts from fine to coarse substrates in both former impoundments. However, we found no significant habitat changes in downstream free-flowing sites, despite field observations that indicated increased bed sediment just following dam removal, with greater deposition in the vicinity of the second, downstream-most removed dam (Woodside II). As expected, previously lentic-dominated communities at former impounded sites generally shifted to a lotic-dominated structure following dam removal within 6-months (upper-removed dam), and 9 months (lower-removed dam). There was some evidence that dredging efforts at the lower dam (Woodside II) were not as effective as those at the upstream dam

(Woodside I), as fish and invertebrate communities appeared to be affected below the lower dam for one to two years following its removal.

Prior to dam removal we routinely captured Bartram's Bass *Micropterus* sp. *cf. cataractae* at all sites (formerly known as Redeye Bass *M. coosae*). Immediately following dam removal we observed the presence of Alabama Bass *Micropterus henshalli*, a species that can reduce native Bartram's Bass populations through introgressive hybridization. Twelvemile Creek is a tributary to Lake Hartwell where Alabama Bass were introduced in the 1980s. This highlights the potential for tributary dams to act as barriers that protect native lotic species from the influence of reservoir taxa; however, the reference tributary Three and Twenty Creek also saw increased presence of Alabama Bass in the period following dam removal on Twelvemile, so this dynamic may be unrelated to dam removal.

Our study demonstrates that dam removal can reverse many of the effects dams have on aquatic biota, primarily through the restoration of high-quality lotic habitats required by native riverine species. Although dam removal has short-term ecological disturbance trade-offs on aquatic habitats and communities, this study suggests that ecosystems in high-gradient southeastern U.S. rivers are likely to recover relatively quickly once habitat disturbances and sediment loads are fully reduced, assuming highly vulnerable or sensitive species are not at risk.

The full introductory, methods, results, and discussion sections describing this 10-year investigation can be found in the Completion Report by the same name as above, submitted in June 2017.

Prepared By: Mark Scott, Kevin Kubach, Andrew Gelder

Title: Fisheries Biologists

Job Title: SC Small River Conservation Planning Project

Period Covered July 1, 2016 – June 30, 2017

Summary

Over the reporting period, we continued site reconnaissance and data collection for the Small River Assessment. Nineteen (19) sites were sampled during the reporting period within two ecobasins: Savannah-Uplands and Santee-Uplands.

Introduction

In South Carolina, high quality aquatic habitats support a rich fauna. The rivers and streams of the southeastern United States have the highest known diversity of mussels, snails and crayfishes in the world. In addition, freshwater fish species richness is the highest of any temperate region and the herpetofauna is globally significant. South Carolina's State Wildlife Action Plan (SWAP) contains descriptions of over 125 species of fish, herpetofauna, mussels, crayfish and snails that are directly dependent on freshwater habitats for most or all of their life-stages, accounting for approximately 40% of the state's total number of species of conservation concern (excluding marine species). The 2015 State Wildlife Action Plan (SWAP) lists 170 species (including leeches, insects, and additional species from the above listed taxa).

This project fits into a grand vision of aquatic conservation in South Carolina that focuses on landscapes and their drainage basins. The first step in building this conservation framework has been largely completed. Through previous State Wildlife Grants, small wadeable streams were assessed during the South Carolina Stream Assessment (SCSA). Data were entered into the StreamWeb database and information served in a web-accessible Stream Conservation Planning Tool. One result apparent from those data is the increase in species richness with stream size, up to the upper size limit in the sample design, which indicates that roughly one species can be expected to be added with every 10 km^2 increase in stream drainage area. It also suggests that a major repository of fish diversity in the state resides in larger streams and small rivers.

The Small River Assessment is intended to extend and further the objectives of the South Carolina Stream Assessment, which was limited to wadeable streams under 150 km^2 in drainage area, in order to include the greater spatial extent of small rivers (up to 2,000 km^2).

Materials and Methods

Sampling Design

A database listing the spatial coordinates and area drained for all 100-m-long segments of every stream and river in South Carolina, compiled for the Stream Assessment project, was used to create a list frame of potential sites from which to select sites for the Small River Assessment. To be included in the list frame, sites had to have a drainage area between 150 and 2000km^2 (Figure 1). Sites were stratified by major river drainage and ecoregion (=ecobasin) and by size (=drainage area). The number of sites apportioned to each strata was proportional to ecobasin area and drainage area, with three size categories defined: Class 4 = 150 to 500 km^2, Class 5 = 500 to 1000 km^2, and Class 6 = 1000 to 2000 km^2 (Table 1).

Results & Discussion

Nineteen (19) sites in two ecobasins (Savannah-Uplands, Santee-Uplands) were sampled during the reporting period (Table 2). Sites (length = 1 km) were sampled using one or more of the following methods as dictated by habitat types present and with target effort expended (i.e. number of replicates) in accordance with standard operating protocols: backpack electrofishing with seine, barge electrofishing, and gill nets (gear evaluations detailed in report covering 2014-2015).

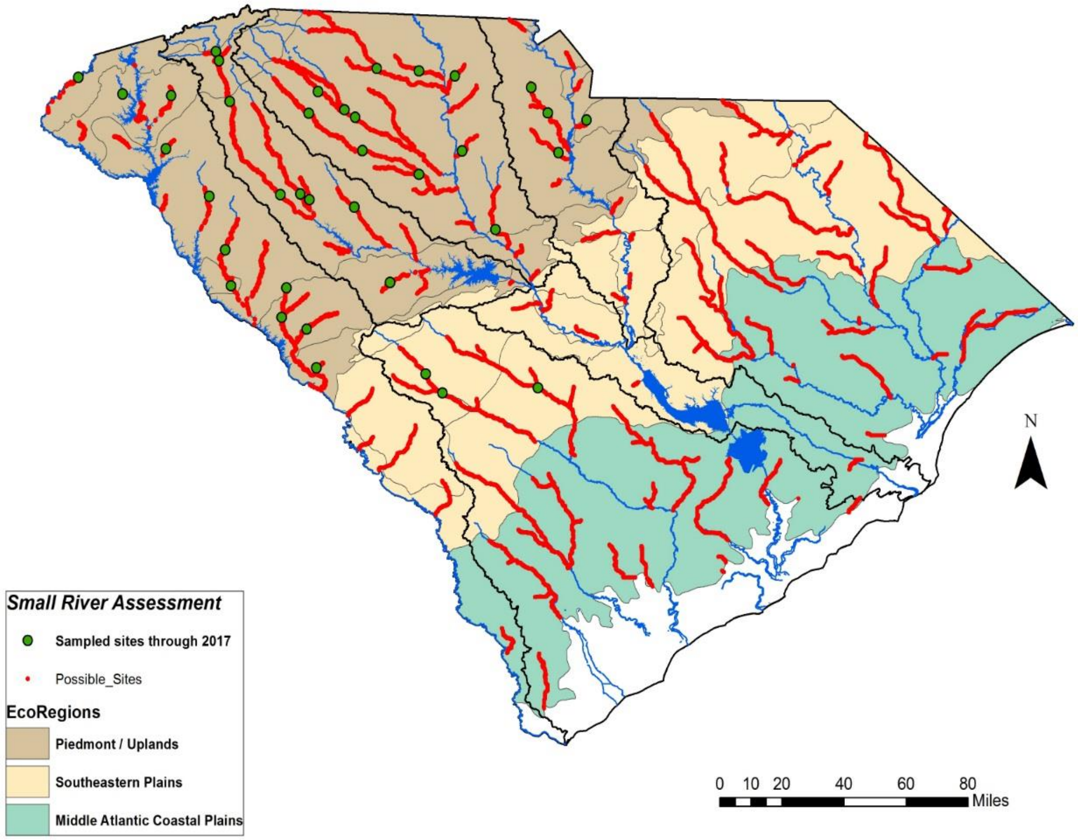

Figure 1. Occurrence of small rivers in South Carolina (red lines), showing Small River Assessment sample sites through 2017 (green points).

Table 1. Sample site allocations (n) by ecobasin for the Small River Assessment. Watershed area size classes are as follows: Class 4 = 150 to 500 km^2; Class 5 = 500 to 1000 km^2; Class 6 = 1000 to 2000 km^2. Note that the sum of watershed class targets (n) may exceed the totals for spatial strata; adjustments will occur during the site selection process based on watershed class availability.

ECOBASIN	Area (km^2)	n total	n (size 4)	n (size 5)	n (size 6)
UPLANDS					
Savannah Basin	8179.81	11	8	3	1
Santee Basin	20178.29	23	16	6	3
Pee Dee Basin	710.58	1	1	1	1
Uplands Total	**29068.68**	**35**			
SOUTHEASTERN PLAINS					
Savannah Basin	2554.95	4	3	1	1
ACE Basin	5686.2	8	6	2	1
Congaree/Lower Santee Basin	5149.23	7	5	2	1
Pee Dee Basin	10210.12	14	10	4	2
Southeastern Plains Total	**23600.5**	**33**			
MIDDLE ATLANTIC COASTAL PLAIN					
Savannah Basin	848.71	2	2	1	1
ACE Basin	10637.4	15	11	4	2
Congaree/Lower Santee Basin	1588.63	3	3	1	1
Pee Dee Basin	8804.66	12	9	3	2
Mid Atlantic Coastal Plain Total	**21879.4**	**32**			
Total	**74548.58**	**100**	**69**	**22**	**9**

Table 2. Small River Assessment sites sampled between 01 July 2016 – 30 June 2017. Ecobasin codes are Savannah-Uplands (SAVUPL) and Santee-Uplands (SANUPL).

Site ID	Date	Size Class	Site Name	Ecobasin	Elevation (ft)	Area (km^2)
123324	7/6/2016	4	Rocky River	SAVUPL	540	278.5
80771	7/7/2016	4	Three and Twenty Creek	SAVUPL	680	187.2
204321	7/19/2016	4	Hard Labor Creek	SAVUPL	415	169.2
169080	7/27/2016	4	Little River	SAVUPL	410	380.9
202204	7/28/2016	5	Little River	SAVUPL	335	798.8
38462	11/2/2016	4	Little River	SAVUPL	700	190.7
26306	11/10/2016	4	Chattooga River	SAVUPL	1560	169.5
107072	7/20/2016	4	Duncan Creek	SANUPL	315	301.8
134474	7/26/2016	4	Little River	SANUPL	435	218.2
51726	8/3/2016	4	North Tyger River	SANUPL	515	446.8
36457	8/4/2016	4	South Tyger River	SANUPL	590	294.0
81633	8/9/2016	4	Sandy River	SANUPL	300	269.5
14073	8/16/2016	4	South Saluda River	SANUPL	940	270.1
22175	10/25/2016	4	North Saluda River	SANUPL	721	193.0
24557	5/30/2017	4	Lawsons Fork Creek	SANUPL	541	218.8
31549	6/1/2017	4	Bullock Creek	SANUPL	430	281.9
26184	6/13/2017	4	Thicketty Creek	SANUPL	460	290.8
43414	6/15/2017	5	Saluda River	SANUPL	787	867.5
122116	6/27/2017	6	Saluda River	SANUPL	480	1495.7

Data are currently being entered and analyzed to estimate occupancy, relative abundance and habitat associations of freshwater fish in South Carolina small rivers. Data will furthermore be integrated with the existing modeling framework developed from the SC Stream Assessment (2006-2011) in smaller (wadeable) streams, allowing decision support for conservation of aquatic resources.

Due to the extensive linear coverage of small rivers across SC and thus proximity to many anglers, these waters represent popular yet understudied sport fisheries. To assess game fish population structure and growth in small rivers, total length (mm) and weight (g) data were obtained from 947 individuals representing 21 species in the following groups of game fish and other recreational angling targets: sunfishes (*Lepomis* sp.), black basses (*Micropterus* sp.), crappies (*Pomoxis* sp.), pikes (*Esox* sp.), catfishes (Ictaluridae) and Yellow Perch (*Perca flavescens*).

Sample sizes were sufficient to facilitate a preliminary length-weight analysis for the following four species: Redbreast Sunfish (*Lepomis auritus*), Bluegill (*Lepomis macrochirus*), Largemouth Bass (*Micropterus salmoides*), and Green Sunfish (*Lepomis cyanellus*; Table 3). Simple linear regression models were constructed from log- transformed length-weight data using the lm() command in the RStudio statistical environment (RStudio Team, 2016) and plotted using the ggplot2 package (Wickham, 2009; Figures 2-9). 95% confidence intervals were constructed about the model slope estimate for each species by river basin to provide a preliminary evaluation of potential differences in growth rate and condition of fish among basins (i.e., weight gain per unit increase in total length). Although sampling is not complete among all ecobasins and river sizes varied widely among sampled regions, these comparisons are presented here as a preliminary exercise. Standardization by habitat types and river sizes and correction for seasonal effects will be investigated in future analyses.

Table 3. Sample size (n) by species for preliminary length-weight analysis of game fish from the Small River Assessment.

	River Basin			
	ACE	**Santee**	**Savannah**	**Total**
Redbreast Sunfish	22	252	78	352
Bluegill	19	132	31	182
Largemouth Bass	23	32	23	78
Green Sunfish	0	40	27	67

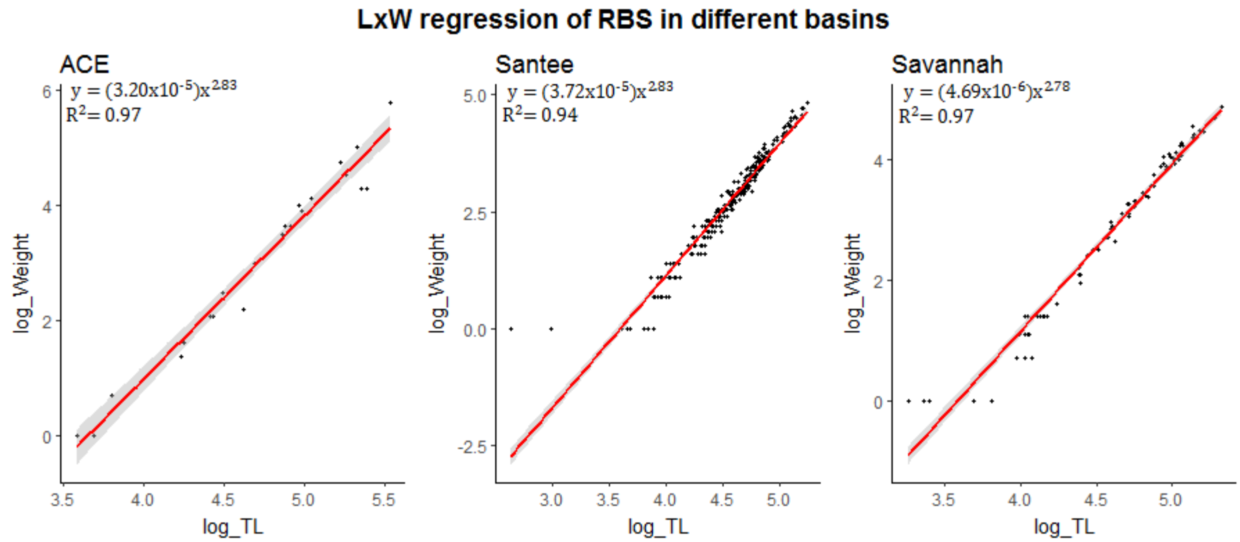

Figure 2. Length-weight regression (log-transformed) for Redbreast Sunfish by river basin.

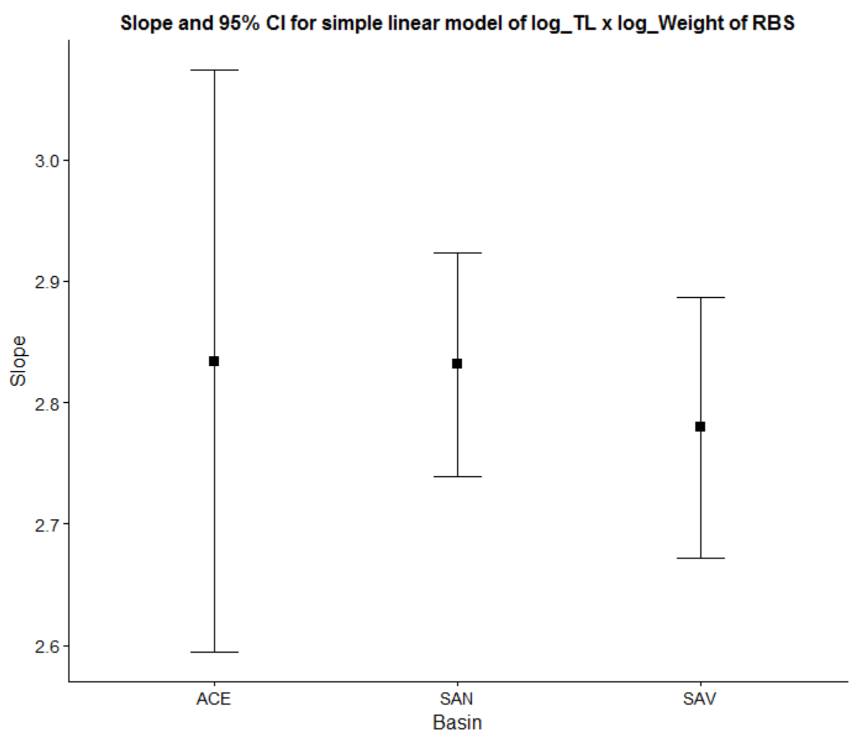

Figure 3. Slope estimates and 95% confidence intervals from linear regression model of log-transformed length x weight for Redbreast Sunfish, by river basin.

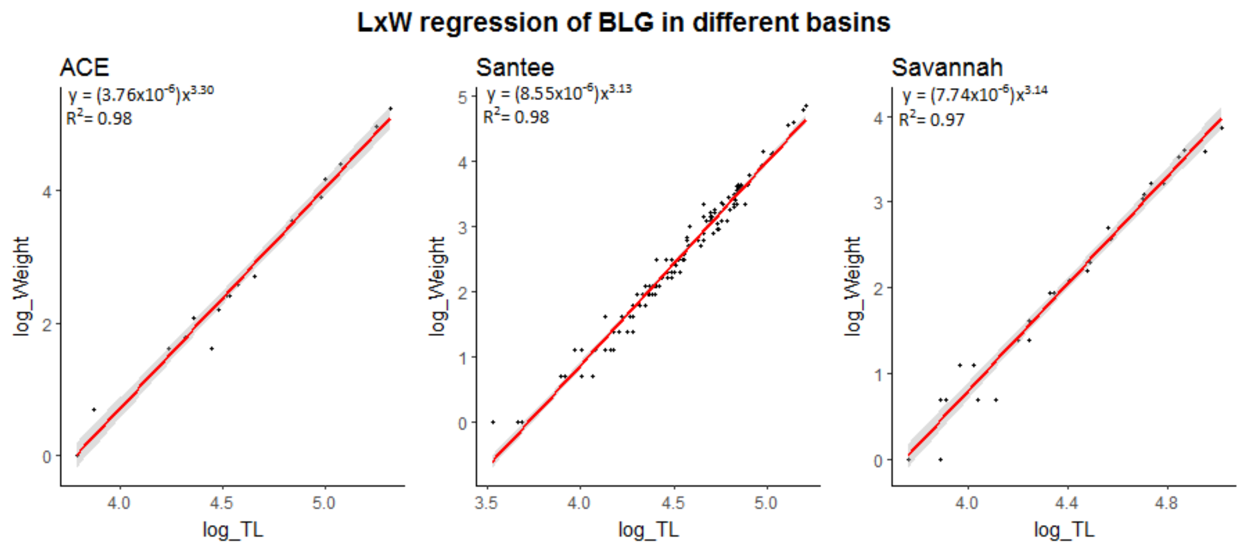

Figure 4. Length-weight regression (log-transformed) for Bluegill by river basin.

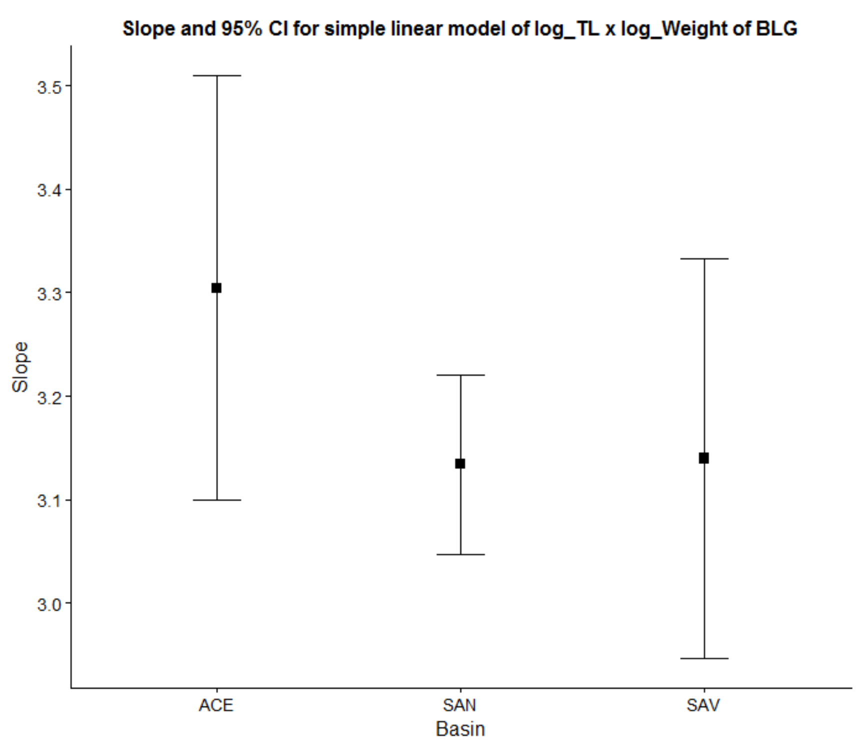

Figure 5. Slope estimates and 95% confidence intervals from linear regression model of log-transformed length x weight for Bluegill, by river basin.

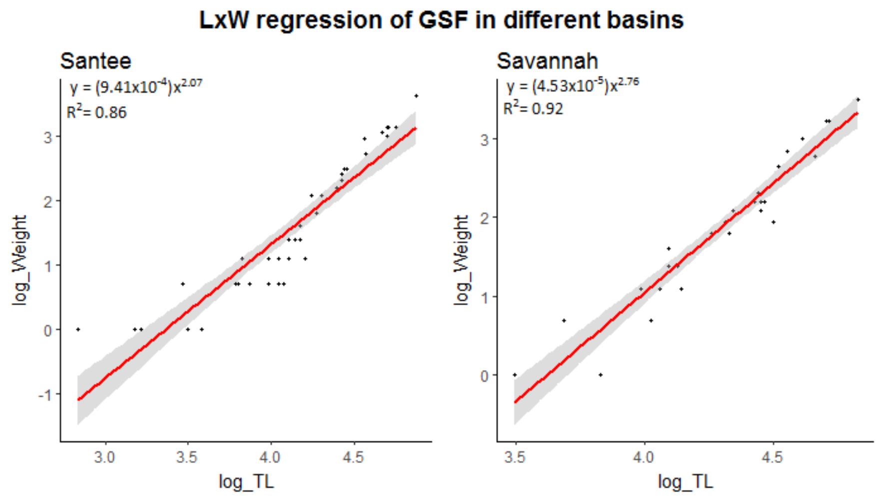

Figure 6. Length-weight regression (log-transformed) for Green Sunfish by river basin.

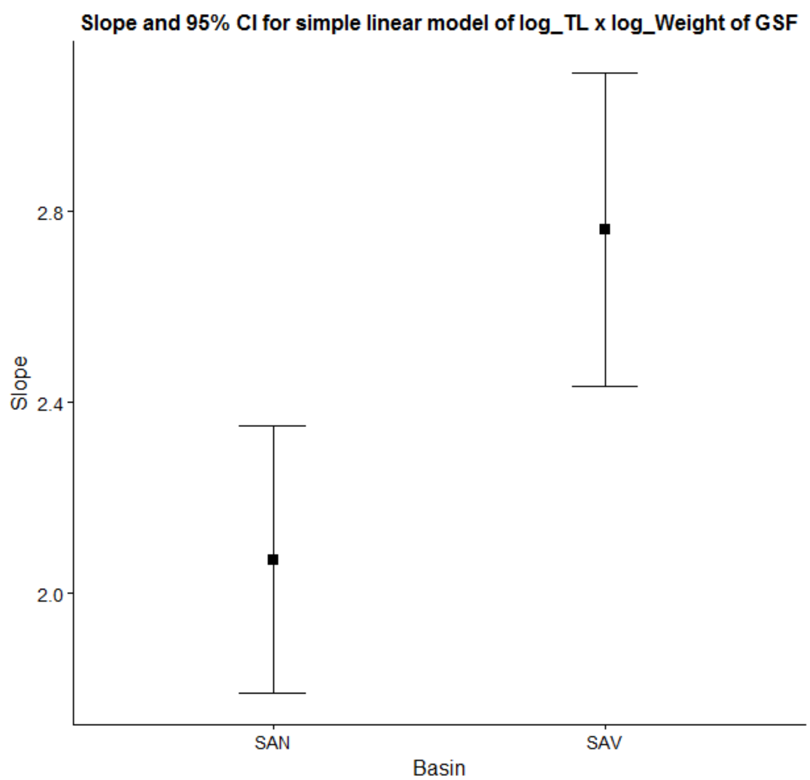

Figure 7. Slope estimates and 95% confidence intervals from linear regression model of log-transformed length x weight for Green Sunfish, by river basin.

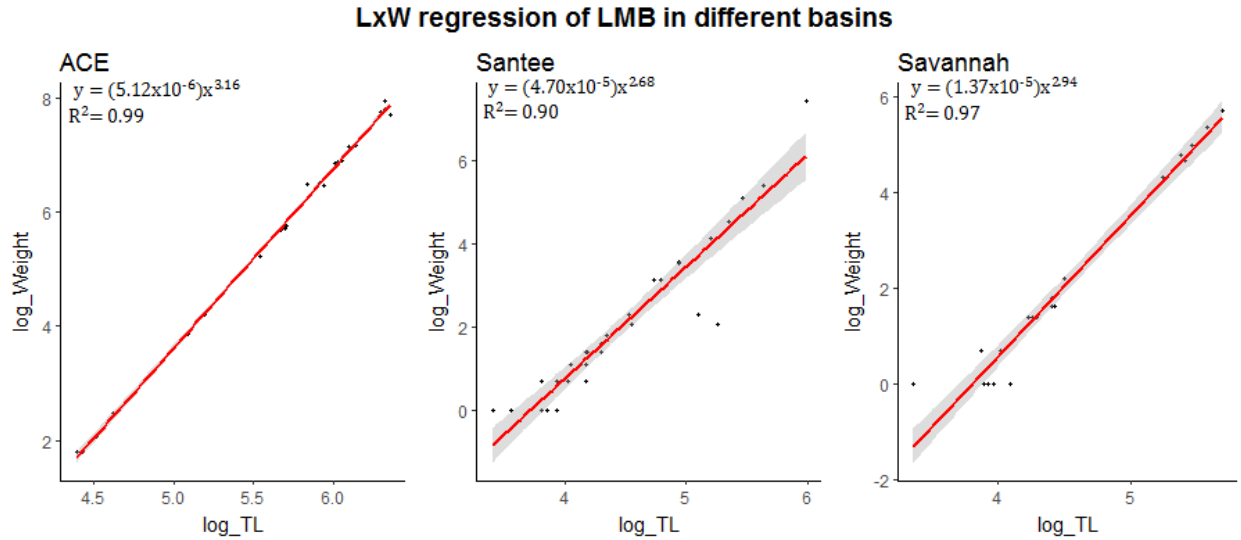

Figure 8. Length-weight regression (log-transformed) for Largemouth Bass by river basin.

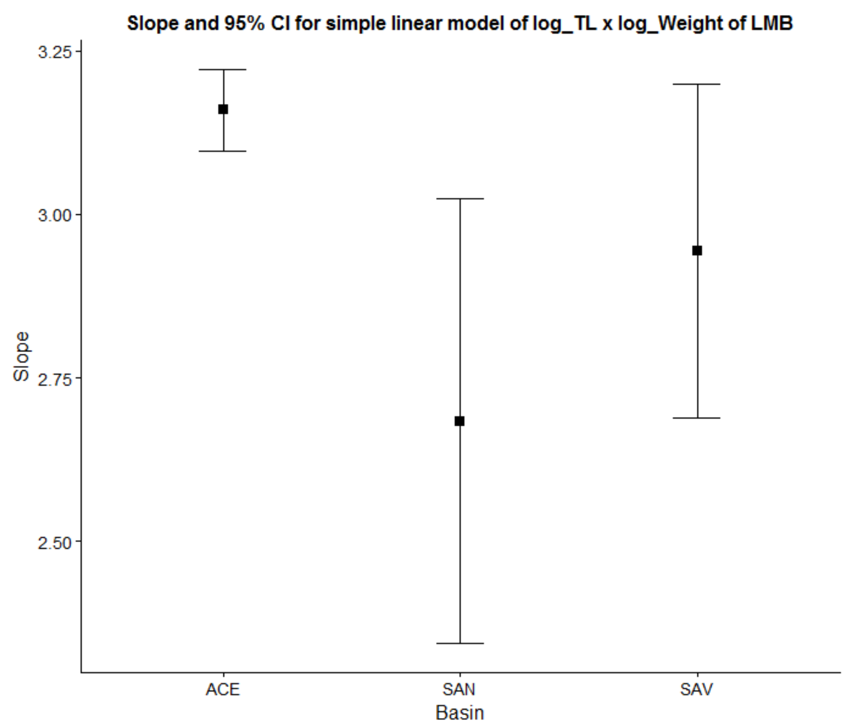

Figure 9. Slope estimates and 95% confidence intervals from linear regression model of log-transformed length x weight for Largemouth Bass, by river basin.

For Redbreast Sunfish and Bluegill, the length-weight slope estimates and confidence intervals show considerable overlap among all three river basins examined, indicating similar weight gain per unit increase in length among basins (Figures 3 and 5). Green Sunfish *Lepomis cyanellus*, a non-native species, showed an apparent difference in growth rate between basins, with fish in the Savannah basin exhibiting greater weight gain per unit increase in length than those in the Santee basin (Figure 7). Varying growth rates in Green Sunfish among basins may be of interest in the context of competition with and predation on native species, among other reasons. Largemouth Bass exhibited similar growth rate between the Santee and Savannah basins (Figure 9); growth rate of this species was apparently greater in the ACE basin than the Santee basin, although it is important to note that the ACE basin was represented by a small sample of relatively large fish from deep rivers possessing ideal habitat for this species.

This analysis represents a preliminary examination of a relatively modest dataset in progress. The examination of length/weight relationships among game fish species in small rivers and potential patterns or differences among spatial strata will become more robust as sampling continues. Potential investigations include differences in growth and size structure among river basins, ecoregions, and river size/watershed area; also of relevance are potential broader patterns and relationships between game fish growth in small rivers and those observed among the same species in managed lakes, reservoirs and larger rivers within these river basins.

Recommendations

This report covers the second year of data collection for the Small River Assessment. Data are currently being entered and analyzed in collaboration with Clemson University to estimate occupancy, relative abundance and habitat associations of freshwater fish in South Carolina small rivers. Data will furthermore be integrated with the existing modeling framework developed from the SC Stream Assessment (2006-2011) in smaller (wadeable) streams, allowing decision support for conservation of aquatic resources. Sampling will continue in all ecobasins as defined in the study design.

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Wickham, H. 2009. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag, New York.

Prepared By: Kevin Kubach, Mark Scott, Drew Gelder, Kenson Kanczuzewski

Title: Wildlife Biologists

Job Title: Development and implementation of an environmental DNA (eDNA) monitoring tool for Blackbanded Sunfish populations in South Carolina and Georgia with determination of relative abundance, genetic health, and connectivity of extant populations

Period Covered July 1, 2016 – June 30, 2017

Summary

As part of Multi-State Wildlife Grant SC-U2-F14AP00997, we continued data collection for a study developing an environmental DNA (eDNA) monitoring tool for a species of conservation concern, Blackbanded Sunfish *Enneacanthus chaetodon*. These statements summarize work done by FWF Research Staff on the project during the report period; additional accomplishments by MRD and GADNR collaborators can be found in the SWG Interim Report for the project.

Introduction

The intent of our project is to provide a comprehensive and proactive assessment of *Enneacanthus chaetodon* distribution, relative abundance, and genetic health of SC and GA populations. We will achieve our goal through the development and application of a new eDNA tool combined with traditional surveys and population genetics. The specific project objectives and their quantifiable metrics include:

1) develop and test an eDNA detection tool for *E. chaetodon*: number of primers tested, number of species amplifying with primers, completion of laboratory experiments, eDNA sampling of four known *E. chaetodon* locations, analysis of test results to determine optimal eDNA sampling protocols.

2) use the eDNA tool to conduct field surveys in appropriate *E. chaetodon* habitats throughout SC and GA.

Materials and Methods

Freshwater Fisheries staff time was devoted to Objective 2, field surveys of appropriate *E. chaetodon* habitats in SC. In April 2016, we collected water (eDNA) samples and habitat characterization data at 30 sites (26 randomly selected and 4 historic *E. chaetodon* localities) across the Sand Hills and Atlantic Southern Loam Plains ecoregions (all river basins) of South Carolina, following protocols developed during Year 1 of the study. Our field protocol was developed in conjunction with MRD and GADNR staff to ensure standardized procedures. During the eDNA survey, water quality characteristics are documented at the site level and comprise water temperature, pH, dissolved oxygen, conductivity, turbidity, and water color. A total of 10 replicate 2 L surface water samples are collected across all of the sample sites. Decimal degree GPS coordinates, time of sampling, substrate type, depth, current velocity, debris type, photos, and vegetation type are documented within a 1 meter grid at all 10 individual water sampling locations. Water body widths are measured at every 5^{th} replicate water sample taken at each site. All water samples are taken prior to disturbing the area and caution is taken not to cross contaminate samples within a site and samples between sites. All materials which are to contact water at a site prior to water samples being taken (waders, boots, etc.) are decontaminated with 10% bleach and rinsed with DI water between each site.

Additional methodologies for the study are found in the Freshwater Fisheries Research annual progress reports covering the periods 2014-2016, as well as the SWG Interim reports by SCDNR-MRD on laboratory methods and results.

Results and Discussion

E. chaetodon DNA was detected at nine of 30 sample sites in South Carolina—one site in the Savannah basin, four in the Edisto, and four in the Pee Dee (Figure 1). Among DNA-positive sites, number of positive bottles (maximum = 10 per site) ranged from 8 to 10 (Table 1). DNA-positive sites represented a range of habitat types including flowing streams, swamps, beaver impoundments, and man-made mill ponds. The range of habitat types supporting *E. chaetodon* was illustrated by the frequency of mean current velocities (i.e. flow) among DNA-positive sites (Figure 2). Although the majority of positive sites were characterized by low velocities (<0.05 m/s), *E. chaetodon* was also detected in sites exhibiting velocities up to 0.37 m/s.

In April 2017, all nine sites yielding positive DNA detections were sampled to validate the presence of *E. chaetodon* and obtain tissue samples for population genetics analysis. Sites were sampled using multiple methods including dip netting, backpack electrofishing, and overnight trapping.

E. chaetodon was confirmed at all nine DNA-positive sites in SC. Total catch (not standardized for sampling effort) ranged from 3 to 34 individuals; abundance showed an apparent relation to habitat type, with densely vegetated ponds exhibiting higher *E. chaetodon* densities and catch rates than natural swamps and streams. Of note were the several cases in which *E. chaetodon* was not collected from the immediate areas in which DNA-positive water samples were taken or was only collected in these areas in low abundance, but was subsequently observed in markedly greater abundance farther upstream, from hundreds of m to several km away. For example, despite extensive sampling effort at one stream site, *E. chaetodon* was not collected in the section where positive water samples were taken; however, it was present in relatively high abundance in the first mill pond upstream of and draining into the site, 2.5 km upstream. These observations suggest potential transport of viable DNA over relatively long distances (at least up to several km) and illustrate the challenges of relating DNA detection to fish proximity and abundance in complex aquatic systems such as coastal plain stream/swamp networks (i.e., Did the DNA originate from relatively few individuals nearby that were simply difficult or impossible to detect with traditional sampling methods, or did it come from a very abundant population farther upstream?).

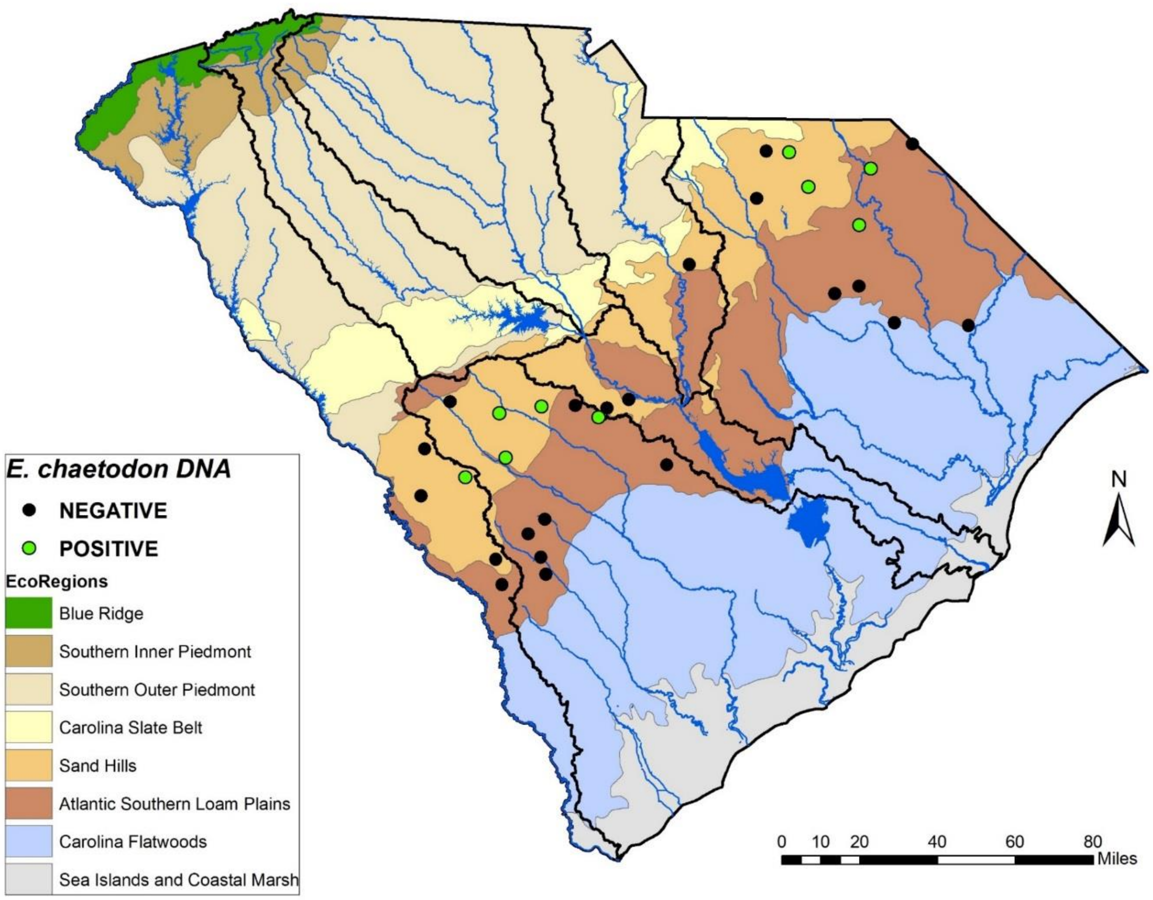

Figure 1. Environmental DNA (eDNA) sample sites (n=30) in South Carolina, showing *E. chaetodon* DNA detection results from water samples taken in April 2016. *E. chaetodon* presence was validated with traditional sampling methods at all nine DNA-positive sites in April 2017.

Table 1. *Enneacanthus chaetodon* DNA detection summary among bottles within DNA-positive sites in South Carolina and Georgia. Ten samples (bottles) were collected per site.

POSITIVE SITES ONLY	**SC**	**GA**
Positive Sites	9	5
Positive bottles (total)	86	7
Negative bottles (total)	4	42
Range: Positive bottles per site	8 - 10	1 - 2

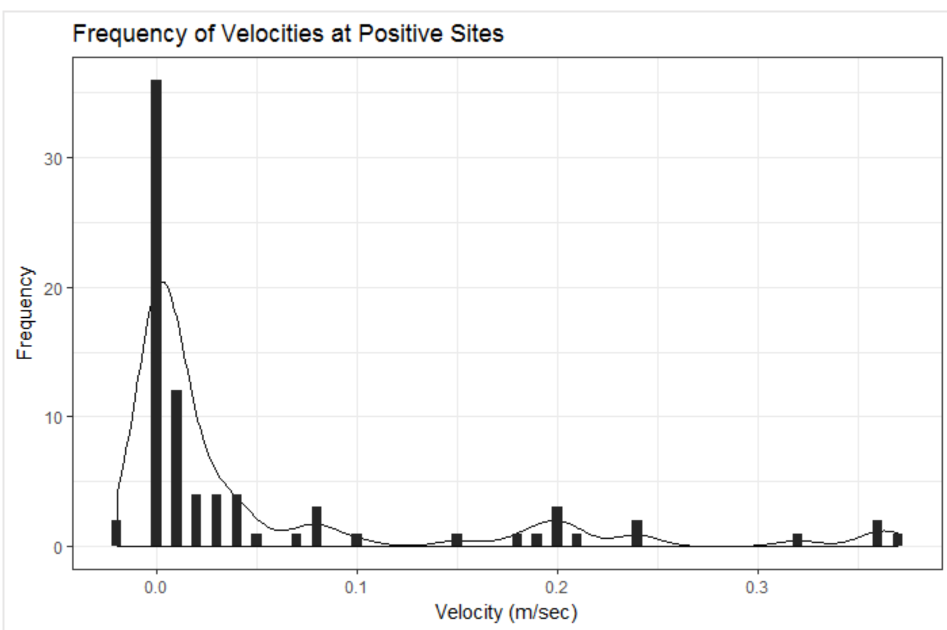

Figure 2. Frequency of mean current velocities among the nine *E. chaetodon* DNA-positive sites in South Carolina.

Recommendations

Proceed with study according to schedule. A database has been developed to house the data associated with this study and, once populated, will facilitate various analyses including *E. chaetodon* habitat associations and population genetics.

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Title: Wildlife Biologists

Job Title: Growth Dynamics of White Perch in South Carolina: Implications for Management

Period Covered July 1, 2016 – June 30, 2017

Summary

An initial survey of growth of White Perch *Morone americana* in select South Carolina reservoirs was conducted during a summer internship using opportunistically obtained samples, mainly from anglers. Results indicated that White Perch have substantial variation in growth within an age cohort. As White Perch are a substantial component of the fishery in several reservoirs, these results suggest that consideration should be given to a protective slot limit regulatory strategy.

Introduction

White perch is primarily a brackish water fish found along the Atlantic slope from Nova Scotia to South Carolina. Freshwater populations are found in coastal lakes and ponds throughout its range, but, historically, were more common in northern areas (Lee et al., 1980). Warren et al. (2000) considered that White Perch were native as far south as the Pee Dee River, South Carolina.

In recent times, White Perch have invaded substantial areas of the United States, spreading into several Midwest states and the lower Great Lakes, further expanding their range (Zuerlein 1981, Jenkins and Burkhead 1994). In South Carolina, White Perch were first noted in inland impoundments in the latter half of the 1970s; it is now found throughout most of South Carolina, including the vast majority of major inland impoundments (Rohde et al. 2009). Marcy et al. (2005) speculated that White Perch accidently stocked into Clarks Hill/J. Strom Thurmond Lake, on the border of Georgia and South Carolina, was responsible for the population now present in the lower Savannah River.

The establishment of White Perch in the inland reservoirs of South Carolina has created concern among anglers and fishery managers, yet quickly created a fishery that many anglers are taking advantage of. One concern was that the establishment of this species was often correlated with the decline of White Bass *Morone chrysops* populations in the State's reservoirs. Madenjian et al. (2000) noted reduced recruitment of White Bass in the Great Lakes after White Perch introduction. Another concern expressed by anglers was that the majority of angled White Perch were too small to harvest. Hines (1981) investigated the ecological significance of a stunted White Perch population in Maine. Gosch et al. (2010) compared predation of White Perch in a stunted, where nearly all fish were less than 200 mm TL, and a non-stunted population in Nebraska. Bethke et al. (2014), looking at four North Carolina inland impoundments, suggested that size structure was density dependent.

The regulatory stance towards White Perch in South Carolina has changed since their introduction into inland waters. Prior to 2008, White Perch was considered a game fish in South Carolina with no size limit and a 30 fish possession limit. Currently, White Perch is considered a non-game fish and there are no limits on size or possession. The regulations established for White Perch in other states are very similar, some even taking measures to prevent the further spread of the fish within the state. For example, North Carolina doesn't have a size or creel limit on inland White Perch but they cannot be possessed, transported, or released in waters in and west of Haywood, Buncombe, and Rutherford Counties. Nebraska has an aquatic invasive species program that specifically targets White Perch as an invasive species and not a fishery. Meanwhile, in the northern, native range of White Perch, the fish is targeted by anglers; in Connecticut, for example, White Perch have a minimum length limit of seven inches and a creel limit of 30 fish per angler.

While the introduction of White Perch into the inland impoundments of South Carolina most probably had ecological consequences, this fish is now a major component of inland fish populations and resource managers need additional information on its population dynamics. Prior studies of White Perch were concentrated in the Northeastern United States and Eastern Canada where the temperatures are cooler than South Carolina, which is at the southern extreme of its range. Recently, invasive populations in North Carolina have sparked concern among anglers, prompting an investigation into their own reservoirs (Feiner et al. 2013). Despite the southern expansion of the White Perch, South Carolina's information on White Perch is limited. Thus, the objective of this survey was to define the growth dynamics of White Perch in four major South Carolina reservoirs. A better understanding of this important population parameter should improve the ability to manage this species effectively in South Carolina and in other, warmer regions of the country where White Perch have become established.

Materials and Methods

White Perch were collected from three reservoirs in South Carolina: Wateree (5,548 ha), Murray (20,639 ha), Monticello (2,752 ha), and the Santee-Cooper system, which contained two major reservoirs, Lakes Moultrie (24,443 ha) and Marion (44,758 ha), and an inflowing river, the Congaree (de Kozlowski et al. 1983). Of special note, Lake Monticello was a cooling reservoir for a nuclear electrical generating facility. Thus, a portion of Monticello reservoir received heated water throughout the year; approximately 14% of the lake was in a Nuclear Exclusion Zone not accessible by boaters.

White Perch were opportunistically collected by angling, electrofishing, and gillnetting. Anglers were told to fish normally, so they may have targeted larger fish. Angling occurred at every site and was the sole source of data for Murray and Monticello. Electrofishing with approximately four amperes of pulsed direct current was conducted on the Congaree River and Lake Wateree with a boat equipped with a Smith-Root GPP electrofisher. Experimental gillnets with bar meshes ranging from 5.08 to 15.24 cm were used in the Santee Cooper system; fish > 200 mm TL were targeted with this method. Once collected, fish were either placed on ice or immediately measured. Weight (g) and total length (mm) were measured and recorded for all fish. Weights and lengths were converted to log10 units and linear regression was used to define a length-weight relationship. Following the standard length determinations of Bister et al (2000), we defined the minimum length at which White Perch would recruit to angler harvest as 200 mm TL. Sagittal otoliths were removed for later aging.

In the lab, sagittal otoliths were embedded in Epofix embedding resin (Electron Microscopy Services, Hatfield, PA) and then cross-sectioned along the transverse plane with an Isomet saw. Sectioned otoliths were mounted on a microscope slide using super glue and were subsequently sanded and polished (Secor et al. 1991). Two independent, experienced readers aged the sectioned otoliths. Any otoliths that were not agreed upon were discarded. It was assumed that the birth date of all fish was April 1. Age was defined by rounding to the nearest age. Mean length at age, and associated standard errors, were determined for White Perch in each of the four reservoirs. Individual lengths at age were correlated against age for each reservoir. The percentage of individuals in each age class that were ≥ 200 mm TL was determined. To get an initial estimate of overall growth in South Carolina, individual length at age data from the four reservoirs was combined and percentile distributions for length at each age class were determined. Additionally, from this combined data set, we determined the Von Bertalanffy growth curve parameters using Proc NLin in SAS. For Von Bertalanffy analysis, age was rounded to the nearest 0.1 year.

The growth history of individual fish was assessed by back-calculation of length at age using the Fraser-Lee method (DeVries and Frie 1996). Cross-sectioned otoliths were photographed at 25x using a dissecting microscope. The resulting images were imported into ImageJ software (Rasband 2017) for analysis. Utilizing the plug-in ObjectJ, the focus, each annulus, and the otolith edge was marked. Otolith and annulus length were measured along two axes, one was from the focus then along the sulcus while the other went from the focus to the farthest ventral point of the otolith. Linear regression was used to assess the correlation between fish length and otolith length and determine the Fraser-Lee slope and intercept and back-calculated length at age. All distances between annuli were measured and exported as pixel lengths. Data from all sites were combined in this analysis to compensate for missing lengths at certain sites. Where there was an overabundance of data for a specific length class, a random number generator was used to draw a subsample of 10 from that length class. To explore individual fish growth histories, we correlated back-calculated length at age 2 against back-calculated length at age 4.

Results and Discussion

A total of 412 White Perch were opportunistically collected from May of 2015 through February of 2017 (Table 1). Angling was used to supply all samples collected on Lakes Murray and Monticello and 91% of the Lake Wateree collections. Santee Cooper had the most diverse use of methods, utilizing gill netting, electrofishing, and angling, with gill netting providing 59.3% of the samples.

All fish with recorded weights and lengths were combined to produce a composite length-weight relationship for White Perch in South Carolina (Figure 1). The equation was:

$$\mathrm{Log}_{10}\mathrm{Wt}\ (\mathrm{g}) = 3.20 * \mathrm{Log}_{10}\mathrm{TL}\ (\mathrm{mm}) - 5.3012;\ R^2 = 0.94:\ N = 412$$

This equation was used to estimate the average weight for various lengths (Table 2). From this result, we defined the minimum length at which White Perch would recruit to angler harvest as 200 mm TL, where they weighed an average of 115 g; at 250 mm TL, White Perch would more than double in biomass, weighing 236 g.

Table 1. Month and method of collection of White Perch in South Carolina, May 2015 through February 2017. Parenthesis indicates trap net, brackets indicates electrofishing, and unmarked numbers indicates angling.

Month	**Reservoir**			
	Murray	**Santee-Cooper**	**Monticello**	**Wateree**
January		(4)		
February		(37)	79	
March	49	21(1)[38]		
April				
May				[9]
June	38	(25)		92
July				
August		(13)		
September				
October				
November				
December		(6)		
Total	87	145	79	101

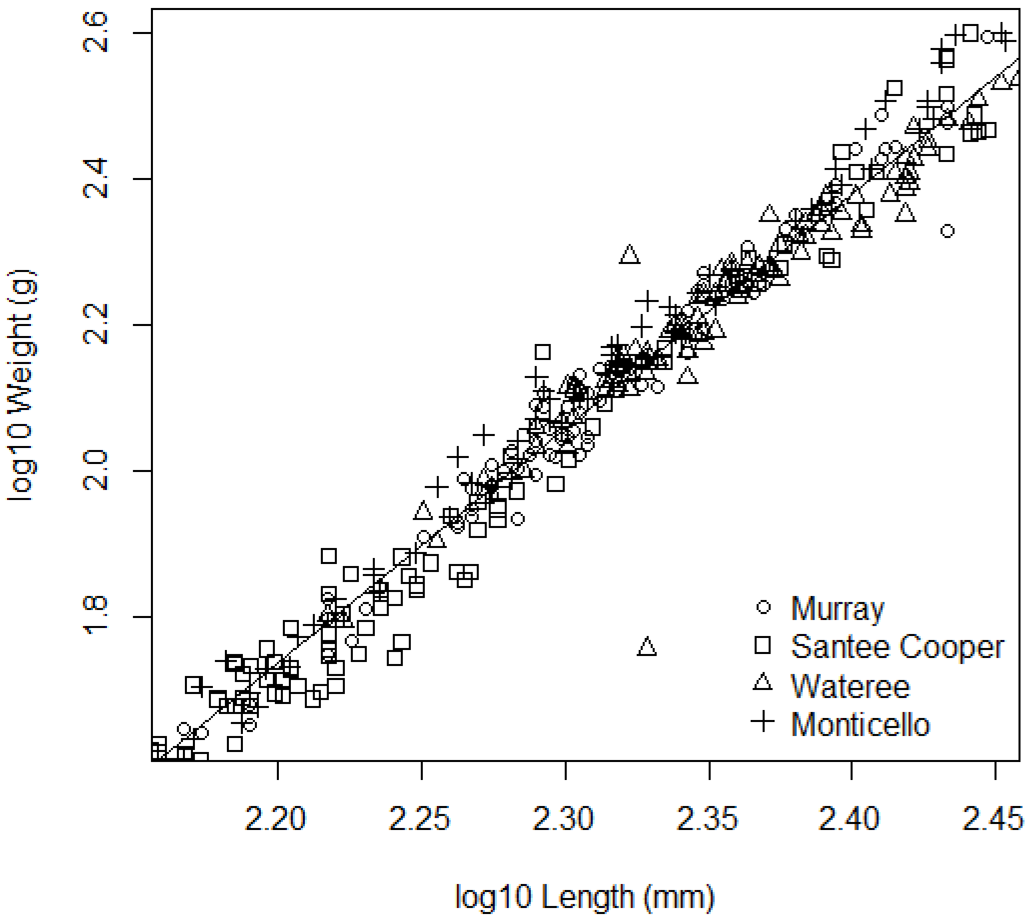

Figure 1: Correlation of $\log_{10}$ length and log10 weight for 412 White Perch collected at four reservoirs in South Carolina.

Table 2: Average weight of White Perch of various lengths, as predicted by a length-weight regression.

Total Length (mm)	Weight (g)	Weight gain (g)
100	13	
125	26	13
150	46	20
175	75	29
200	115	40
225	168	53
250	236	67

High precision was obtained when aging White Perch from sectioned otoliths. Of the 383 otoliths that were inspected, the two readers agreed on 97.9% of the ages.

Mean length at age showed substantial variation among the sampled sites (Table 3). Mean length at age exceeded 200 mm TL at Age IV in three reservoirs; this threshold was reached in Lake Wateree at Age III. In general, the variation in mean length at age was greatest in Lake Monticello where standard errors averaged approximately 10 mm. The White Perch population in Lake Wateree was dominated by Age V individuals, indicating that 2010 produced a dominant year class. Some age classes in the overall collection were poorly represented with ≤ 5 sample. The oldest specimens (N=5) in our samples were eight years old.

Table 3: Mean total lengths in four South Carolina Reservoirs of White Perch. Standard error is provided in parenthesis and total sample size is underneath.

Reservoir	Mean length at age							
	1	2	3	4	5	6	7	8
Murray		185 (5.3)	193 (3.5)	222 (5.0)	237 (5.2)	266 (5.5)		271
		16	28	12	18	2		1
Wateree	129 (4.5)	172 (6.5)	214 (6.0)	180	223 (2.4)	261 (5.9)		271 (8.3)
	2	2	7	1	68	16		4
Santee Cooper	118 (13.5)	134.5 (2.8)	185 (4.6)	246 (8.6)	229 (14.2)	301 (24.5)		
	7	41	55	6	12	2		
Monticello		186 (12.6)	179 (10.1)	218 (7.1)	202 (9.7)	204 (11.0)	203 (23.1)	
		8	6	29	10	19	3	

The variation in length at age class was substantial, especially in Lake Monticello (Figure 2). Lake Murray White Perch exhibited a consistent growth trajectory from Ages II to V; 18.8, 39.3, 91.7, and 94.4% of the fish were ≥ 200 mm TL at Ages II through V. However, at the other extreme, Lake Monticello exhibited a relatively flat, growth trajectory, with 0.0, 16.7, 65.5, and 40% of the fish ≥ 200 mm TL at Ages II through V; at Age VI, only 8 of 19 sampled fish were ≥ 200 mm TL. The Santee-Cooper sample was dominated by Age III fish where 12 of 55 fish were ≥ 200 mm TL. The Lake Wateree sample was dominated by Age V fish where 62 of 68 fish were ≥ 200 mm TL. When data from all sites was combined, percentile distributions showed that some fish were ≥ 200 mm at Age II while the transition from Age III to IV appeared to be where a majority of the fish within an age cohort reached recruitment length of 200 mm TL (Table 4).

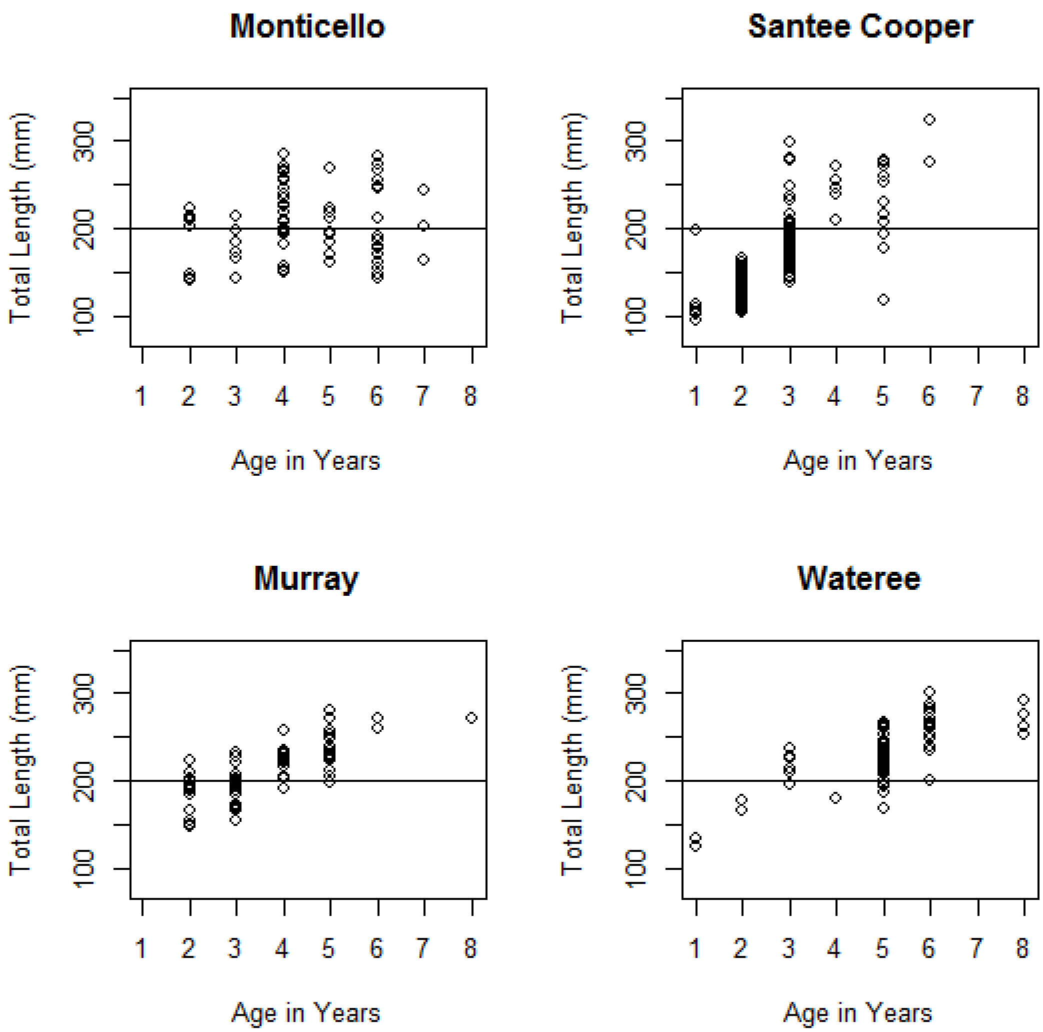

Figure 2: The total length of each aged fish with a line indicating recruitment to the fishery at 200 mm TL.

Table 4: Percentile distributions of mean lengths (mm) of White Perch at 1 to 6 years old among 4-four reservoir populations in South Carolina.

Age	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**
1	98	101	103	108	120	146	172
2	108	112	131	148	165	202	210
3	152	159	167	186	200	227	236
4	156	181	201	223	240	266	270
5	184	194	208	223	237	261	270
6	153	160	189	253	266	283	288

A Von Bertalanffy curve was derived using all of the length at age data to gain an initial understanding of the growth of White Perch in South Carolina. The resulting formula was:

$$TL_{(t)} = 258.393\left(1 - e^{-0.382\,(t-0.458)}\right);\ R^2 = 0.471:\ N = 375;\ P > 0.05,$$

where TL_t was the total length at age t. When predicted Von Bertalanffy growth was plotted with the data from all sites it was evident that the high variation in length at ages caused the lack of fit, however, the variation in length at age was also evident (Figure 3).

Back-calculation of length at age was done to assess the growth history of individual White Perch collected in this study. It was determined that the otolith length line from the focus to the farthest ventral point produced the best fit; the R^2 for this method equaled 0.74 (N=375), while the line along the sulcus produced an R^2 of 0.41 (N=375). The regression defining the relationship between otolith length to the farthest ventral point and fish length resulted in the formula (Figure 4):

$$TL_{fish} = 0.0641 * TL_{otolith} - 48.151;\ R^2 = 0.7445:\ N=375;\ P < 0.05$$

Lengths at Ages II ($L_{(t=2)}$) and 4 ($L_{(t=4)}$) were correlated (Figure 5) and the resulting linear regression was:

$$L_{(t=4)} = 1.4593 * L_{(t=2)} - 2.3703; R^2=0.7151: N=147: P < 0.05$$

The positive linear relationship indicated that size at a younger age would largely determine size at an older age.

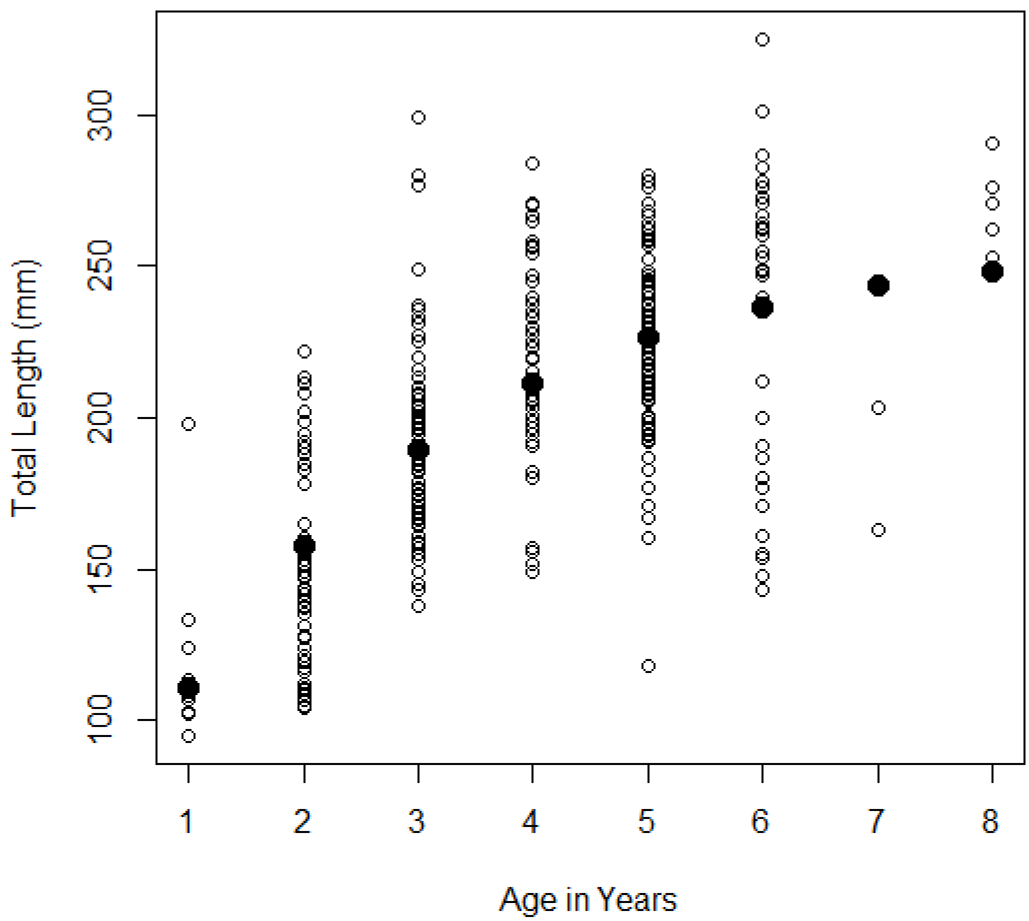

Figure 3: Predicted von Bertalanffy length at age (solid circles) plotted against individual lengths at age (open circles) for 375 White Perch collected from four, South Carolina reservoirs.

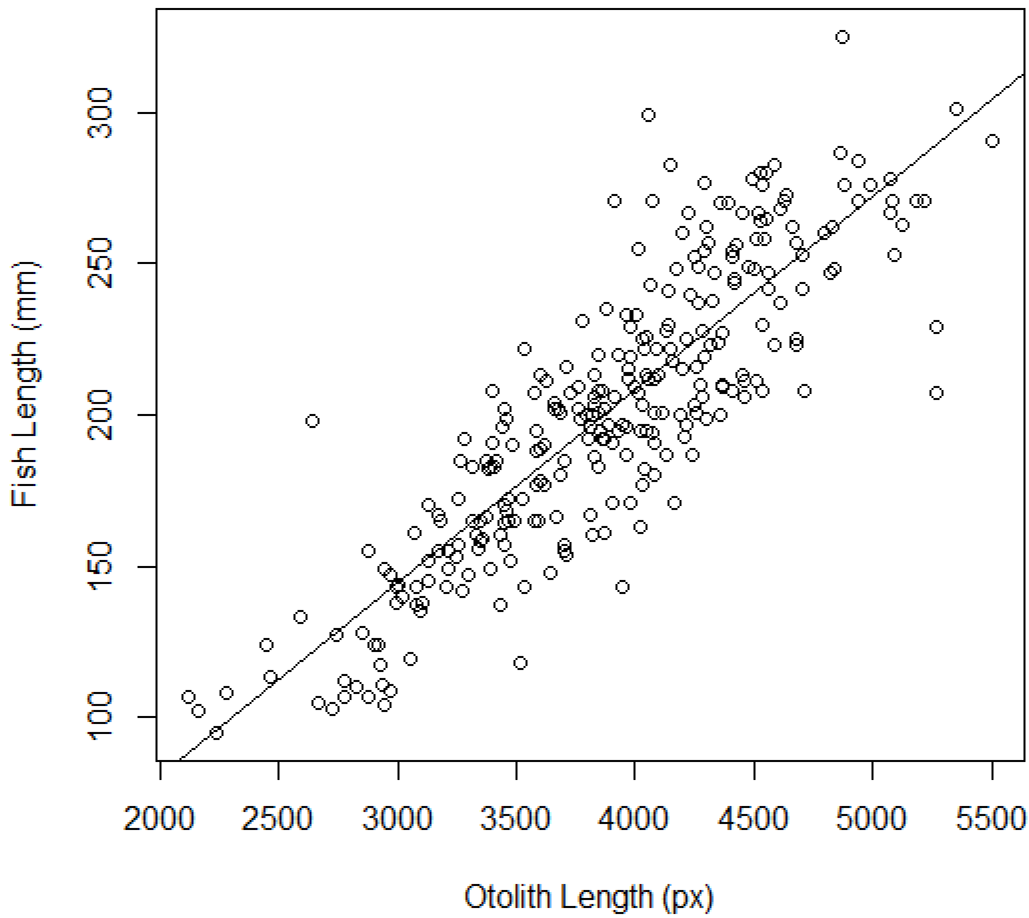

Figure 4: Correlation between White Perch total length and otolith length. The linear regression equation for the relation is provided in the text.

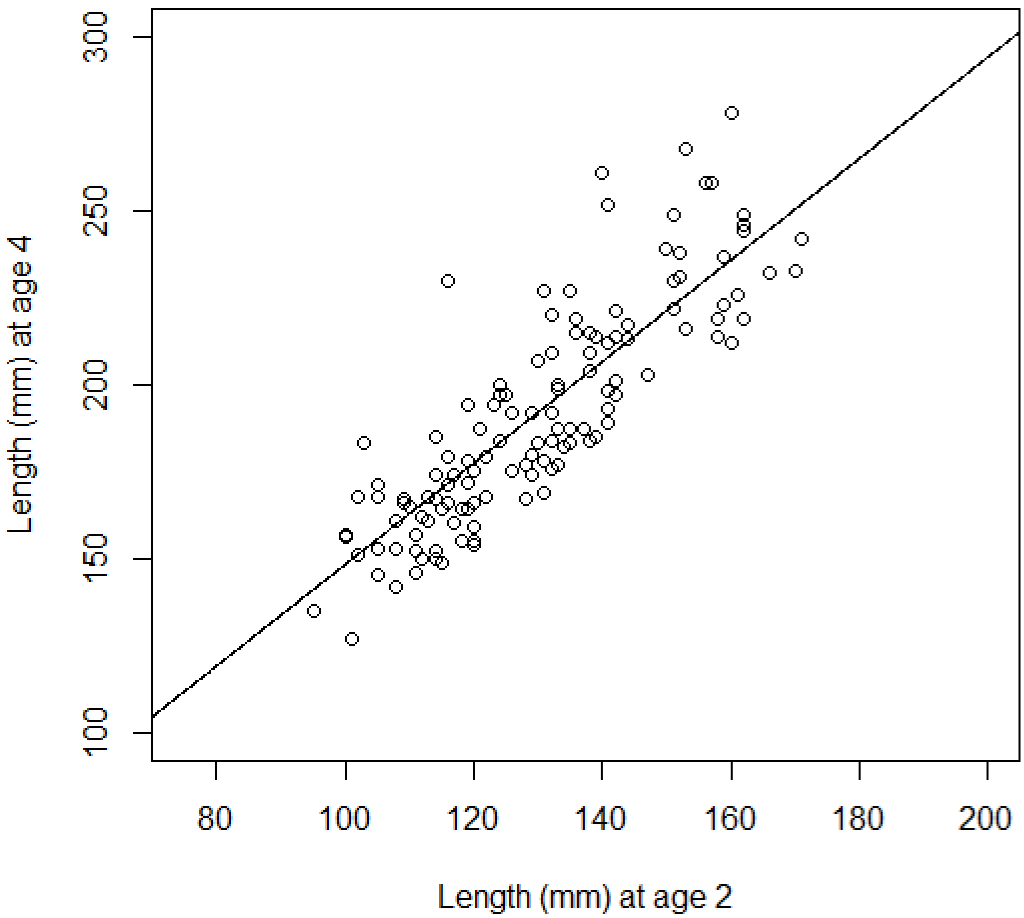

Figure 5. The significant ($P < 0.05$; $R^2 = 0.72$) correlation between length at Age II and length at Age IV from back-calculation estimates for 160 White Perch collected from four South Carolina reservoirs. Fish with back-calculated lengths < 95 mm were eliminated due to limits in the dataset. Number of observations was 57, 20, 22, and 61 from lakes Wateree, Santee-Cooper, Murray, and Monticello, respectively.

Discussion:

Our study indicated White Perch in South Carolina had the ability to reach harvestable size, but there was substantial variability in growth within age cohorts that needs to be considered in future management determinations. For example, when all four study reservoirs were combined, approximately 10% of Age II fish had recruited to the fishery while nearly 25% of Age V fish had not recruited. Mansueti reported similar variability in growth within age classes of White Perch in the Patuxent Estuary, Maryland (1961). Variation in growth within an age cohort is commonly observed among fishes (Jackson et al. 2008), however the consequences of this variation are not often considered in standard management evaluations of freshwater fisheries such as yield per recruit modeling, which uses a single Von Bertalanffy equation to estimate length at time for all individuals (Power 2007).

None of the four sampled populations were classified as stunted. Chizinski (2007) defined a stunted population as having a diminished maximum size due to density-dependent mechanisms that is not genetically determined. In all four reservoirs a segment of the population was able to attain near maximum size for the species.

There are several possible explanations for the underlying cause of growth variation of White Perch in South Carolina reservoirs. Bethke et al. (2014) studied four North Carolina lakes and determined that White Perch size structure appeared to be highly density dependent. In our study, abundance of White Perch was not evaluated so density dependence could not be evaluated. Elliot (2015) demonstrated that mean length of Brown Trout *Salmo trutta* was not density-dependent but mean lengths of the fastest and slowest growing trout were density dependent, suggesting a combination of density-independent and density-dependent factors can affect growth. The possibility exists that only a portion of the population locates favorable habitat or conditions for growth. Danehy et al. (1991) showed that growth rate of White Perch and Yellow Perch was significantly greater for individuals sampled from cobble/rubble shoals as compared to featureless sand sites in Lake Ontario.

Growth variation was greatest in Lake Monticello, a nuclear cooling reservoir, and this may suggest the possible importance of habitat in growth determination. The lower portion of Lake Monticello receives heated discharge, producing warmer than ambient conditions in winter and in summer. Anglers are known to concentrate in this heated area during the winter months. Previous studies indicated White Perch seek out higher temperature patches in reservoirs and grow more when temperatures increase (Hall et al. 1979, Mansueti 1961). This suggests the possibility that only a portion of the population in Lake Monticello located an area of the lake where favorable conditions for growth were present.

The positive correlation between length at Age II and length at Age IV observed in this study suggests a genetic component to the variation in growth. Wang et al. (2006) evaluated the quantitative genetics of growth-related traits in congeneric hybrid Striped Bass *Morone chrysops* ♀ *x Morone saxatilis* ♂ and found high genetic correlation with growth rates, suggesting that growth rate at an early stage could affect growth at a later stage. As South Carolina reservoirs were invaded by White Perch in the last 20 to 40 years, the possibility exists that current populations exhibit genetic characteristics that are intermediate between the invasive and the equilibrium stage of an invasive species. Feiner et al. (2012) evaluated four White Perch populations in different stages of invasion and found life history differences in growth and reproduction that were related to the time since invasion.

This study was intended to obtain an initial look at the growth dynamics of White Perch in South Carolina. Thus, a definitive conclusion cannot be made regarding the mechanisms that drive growth variation. Future studies would need to develop a standard sampling plan, such as developed by Bethke et al, (2014) that exerts equal sampling effort and obtains a representative sample of each cohort within the population. Telemetry studies would also help determine the relative use of favorable habitats for growth over an annual cycle.

Obtained and historical information suggests that White Perch in South Carolina should receive consideration as a sport or commercial species and consideration should be given to alternate management strategies. White Perch have quickly become a substantial portion of the harvest in South Carolina reservoirs. Approximately a decade after their introduction, Bulak et al. (1983) reported the harvest of over 5,000 kg from the Santee-Cooper system in 1983 while Hayes and Penny (1985) reported that White Perch was the third most abundant species in the Lake Murray harvest in 1984. In recent times, nine years of creel survey on Lake Greenwood, South Carolina, from 2007 through 2016 showed that White Perch comprised an average of 22% of the harvest (Weston Houck, SCDNR Biologist, personal communication). Thus, though often maligned, it is obvious that White Perch have become a substantial part of the harvest in South Carolina reservoirs.

Defining a regulation that would both recognize the perceived high abundance of small, non-harvestable individuals and, at the same time optimize the sport fish harvest is a difficult task. The current regulation has no limits on size or possession. This regulation that allows unlimited harvest was enacted because of the concern that the high perceived abundance of White Perch could harm more desirable fisheries, like Striped Bass *Morone saxatilis*, by occupying the same trophic level (Zuerlein 1981, Feiner et al. 2013). The possibility exists that the current regulation is not increasing the overall harvest of White Perch but is increasing the harvest of fast-growing members of each spawning cohort that reach a desirable harvest size. A pattern of selectively harvesting the faster growing individuals would, in the long-term, select for slow-growing animals that are capable of earlier reproduction. White Perch are known to reach sexual maturity at length below 200 mm TL, the size given the Quality designation by Bister et al. (2000). Feiner et al. (2012) showed that the 50% maturity of female White Perch in North Carolina varied between 115 and 165 mm TL, depending on the invasion history of the reservoir.

A protective slot limit has the potential of allowing for unlimited harvest of small, overabundant White Perch yet allow some protection of the reproductive potential of the faster-growing members of each age cohort. Based on available growth, fecundity, and angler preference information, we suggest consideration of a 150 to 225 mm TL protective slot with unlimited harvest below and restricted harvest above the protected slot. This type of regulation would recognize that White Perch are targeted by a segment of anglers, there can be an over-abundance of small, slow-growing fish, and there are fast-growing fish that are desirable and warrant some level of protection from unlimited harvest.

Recommendations

1. Consider conducting fall or winter sampling of White Perch with appropriately-sized experimental gill nets to monitor relative abundance by year class in reservoirs where a significant fishery exists. Within this survey obtain information on age at maturity and additional growth information.
2. Consider a 150 to 225 mm TL protective slot with unlimited harvest below and restricted harvest above the protected slot to encourage harvest of slow-growing animals and protect faster-growing animals prior to attaining desired, harvestable size.

3. Consider recognition of White Perch as a game species as they are a substantial component of the fishery in several reservoirs.

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